1979 YEARBOOK OF ASTRONOMY PATRICK MOORE Sidgwick & Jackson

1979
YEARBOOK of ASTRONOMY

Edited by
Patrick Moore

1979
Yearbook of Astronomy

Edited by

PATRICK MOORE

Sidgwick & Jackson Limited
LONDON

First Published in Great Britain 1978

Copyright © 1978 by Sidgwick and Jackson Limited

Published in Great Britain by
Sidgwick and Jackson Limited
1 Tavistock Chambers, Bloomsbury Way
London WC1A 2SG

0.283. 98479.1 (Hard)
0.283. 98485.6 (Limp)

Printed in Great Britain
by Biddles of Guildford

Contents

Editor's Foreword · 7

Preface · 9

PART ONE: EVENTS OF 1979

Notes on the Star Charts · 13

Northern Star Charts · 16

Southern Star Charts 42

The Planets and the Ecliptic · 68

Phases of the Moon, 1979 · 73

The Planets in 1979 · 74

Events of 1979 · 76

Monthly Notes · 77

Eclipses in 1979 · 124

Occultations in 1979 · 126

Comets in 1979 · 127

Meteors in 1979 · 130

Minor Planets in 1979 · 131

Some Events of 1980 · 132

PART TWO: ARTICLE SECTION

The Shoulders of Giants: *R. Maddison* · 135

George Biddell Airy: *Peter J. Garbett* · 144

Chiron: a New Type of Object in the Solar System: *Charles T. Kowal* · 151

Lunar Transients: Their History and Our Theories: *Michael Bode* · 157

The Atmospheres of Uranus and Neptune: *Garry E. Hunt* · 164

The Story behind the Discovery of the Rings of Uranus: *Gordon E. Taylor* · 177

The "Maunder Minimum" in Perspective: *Cicely M. Botley* 187

Brighter than a Million Suns: *David A. Allen* · 191

Supernovæ in History: *F. Richard Stephenson* · 200

Journey to the Centre of the Galaxy: *Heather Couper* · 211

Recent Advances in Astronomy: *Patrick Moore* · 226

PART THREE: MISCELLANEOUS

Some Interesting Telescopic Variable Stars · 235

Some Interesting Double Stars · 234

Some Interesting Clusters and Nebulæ · 236

Some Recent Books · 237

Our Contributors · 238

Astronomical Societies in Great Britain · 241

Editor's Foreword

The only major change in the style of the 1979 *Yearbook* is that the 'general notes' in the monthly charts have been reinstated; many readers wrote protesting at their omission last year! As always, the charts and the notes of monthly phenomena have been prepared by Dr. J. G. Porter, to whom we are most grateful. The authors of the articles range from those who have contributed often in the past (such as Drs. Allen, Hunt and Maddison) to new writers; we particularly welcome the description of the extraordinary object Chiron, prepared for us by the discoverer, Professor Charles T. Kowal.

We hope that the new edition will be welcomed as warmly as those of past years have been!

PATRICK MOORE

Selsey, 1978

Preface

New readers will find that all the information in this *Yearbook* is given in diagrammatic or descriptive form; the positions of the planets may easily be found on the specially designed star charts, while the monthly notes describe the movements of the planets and give details of other astronomical phenomena visible in both the northern and southern hemispheres. Two sets of star charts are provided. The **Northern Charts** (pp. 16 to 41) are designed for use in latitude 52 degrees north, but may be used without alteration throughout the British Isles, and (except in the case of eclipses and occultations) in other countries of similar north latitude. The **Southern Charts** (pp. 42 to 67) are drawn for latitude 35 degrees south, and are suitable for use in South Africa, Australia and New Zealand, and other stations in approximately the same south latitude. The reader who needs more detailed information will find *Norton's Star Atlas* (Gall and Inglis) an invaluable guide, while more precise positions of the planets and their satellites, together with predictions of occultations, meteor showers, and periodic comets may be found in the *Handbook* of the British Astronomical Association. A somewhat similar publication is the *Observer's Handbook* of the Royal Astronomical Society of Canada, and readers will also find details of forthcoming events given in the American *Sky and Telescope*. This monthly publication also produces a special occultation supplement giving predictions for the United States and Canada.

Important Note

The times given on the star charts and in the Monthly Notes are generally given as local times, using the 24-hour clock, the day beginning at midnight. The times of a few events (e.g.

eclipses) are given in Greenwich Mean Time (G.M.T.), which is related to local time by the formula

Local Mean Time = G.M.T. — west longitude.

In practice, small differences of longitude are ignored, and the observer will use local clock time, which will be the appropriate Standard (or Zone) Time. As the formula indicates, places in west longitude will have a Standard Time slow on G.M.T., while places in east longitude will have Standard Times fast on G.M.T. As examples we have:

Standard Time in

New Zealand	G.M.T.	+	12 hours
Victoria; N.S.W.	G.M.T.	+	10 hours
Western Australia	G.M.T.	+	8 hours
South Africa	G.M.T.	+	2 hours
British Isles	G.M.T.		
Eastern S.T.	G.M.T.	–	5 hours
Central S.T.	G.M.T.	–	6 hours, etc.

If Summer Time is in use, the clocks will have been advanced by one hour, and this hour must be subtracted from the clock time to give Standard Time.

In Great Britain and N. Ireland, Summer Time will be in force in 1979 from 18 March 02^h until 28 October 02^h G.M.T.

PART ONE

Events of 1979

MONTHLY CHARTS and ASTRONOMICAL PHENOMENA

Notes on the Star Charts

The stars, together with the Sun, Moon and planets seem to be set on the surface of the celestial sphere, which appears to rotate about the Earth from east to west. Since it is impossible to represent a curved surface accurately on a plane, any kind of star map is bound to contain some form of distortion. But it is well known that the eye can endure some kinds of distortion better than others, and it is particularly true that the eye is most sensitive to deviations from the vertical and horizontal. For this reason the star charts given in this volume have been designed to give a true representation of vertical and horizontal lines, whatever may be the resulting distortion in the shape of a constellation figure. It will be found that the amount of distortion is, in general, quite small, and is only obvious in the case of large constellations such as Leo and Pegasus, when these appear at the top of the charts, and so are drawn out sideways.

The charts show all stars down to the fourth magnitude, together with a number of fainter stars which are necessary to define the shape of a constellation. There is no standard system for representing the outlines of the constellations, and triangles and other simple figures have been used to give outlines which are easy to follow with the naked eye. The names of the constellations are given, together with the proper names of the brighter stars. The apparent magnitudes of the stars are indicated roughly by using four different sizes of dots, the larger dots representing the bright stars.

The two sets of star charts are similar in design. At each opening there is a group of four charts which give a complete coverage of the sky up to an altitude of 62½ degrees; there are twelve such groups to cover the entire year. In the **Northern Charts** (for 52 degrees north) the upper two charts show the southern sky, south being at the centre and east on the left. The coverage is from 10 degrees north of east (top left) to 10 degrees north of west (top right). The two lower charts show the northern sky from 10 degrees south of west (lower left) to 10 degrees south of east (lower right). There is thus an overlap east and west.

Conversely, in the **Southern Charts** (for 35 degrees south) the upper two charts show the northern sky, with north at the centre and east on the right. The two lower charts show the southern sky, with south at the centre and east on the left. The coverage and overlap is the same on both sets of charts.

Because the sidereal day is shorter than the solar day, the stars appear to rise and set about four minutes earlier each day, and this amounts to two hours in a month. Hence the twelve groups of charts in each set are sufficient to give the appearance of the sky throughout the day at intervals of two hours, or at the same time of night at monthly intervals throughout the year. The actual range of dates and times when the stars on the charts are visible is indicated at the top of each page. Each group is numbered in bold type, and the number to be used for any given month and time is summarised in the following table:

Local Time	18h	20h	22h	0h	2h	4h	6h
January	11	12	1	2	3	4	5
February	12	1	2	3	4	5	6
March	1	2	3	4	5	6	7
April	2	3	4	5	6	7	8
May	3	4	5	6	7	8	9
June	4	5	6	7	8	9	10
July	5	6	7	8	9	10	11
August	6	7	8	9	10	11	12
September	7	8	9	10	11	12	1
October	8	9	10	11	12	1	2
November	9	10	11	12	1	2	3
December	10	11	12	1	2	3	4

The charts are drawn to scale, the horizontal measurements, marked at every 10 degrees, giving the azimuths (or true bearings) measured from the north round through east (90 degrees), south (180 degrees), and west (270 degrees). The vertical measurements, similarly marked, give the altitudes of the stars up to 62½ degrees. Estimates of altitude and azimuth made from these charts will necessarily be mere approximations, since no observer will be exactly at the adopted latitude, or at the stated time, but they will serve for the identification of stars and planets.

The ecliptic is drawn as a broken line on which longitude is marked at every 10 degrees; the positions of the planets are then easily found by reference to the table on page 74. It will be noticed that on the southern charts the ecliptic may reach an altitude in excess of 62½ degrees on star charts 5 to 9. The continuation of the broken line will be found on the charts of overhead stars.

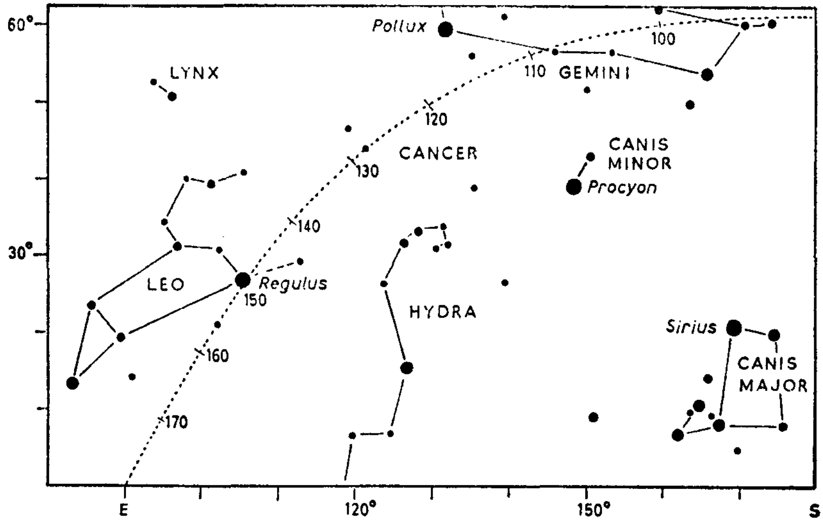
There is a curious illusion that stars at an altitude of 60 degrees or more are actually overhead, and the beginner may often feel that he is leaning over backwards in trying to see them. These overhead stars are given separately on the pages immediately following the main star charts. The entire year is covered at one opening, each of the four maps showing the overhead stars at times which correspond to those of three of the main star charts. The position of the zenith is indicated by a cross, and this cross marks the centre of a circle which is 35 degrees from the zenith; there is thus a small overlap with the main charts.

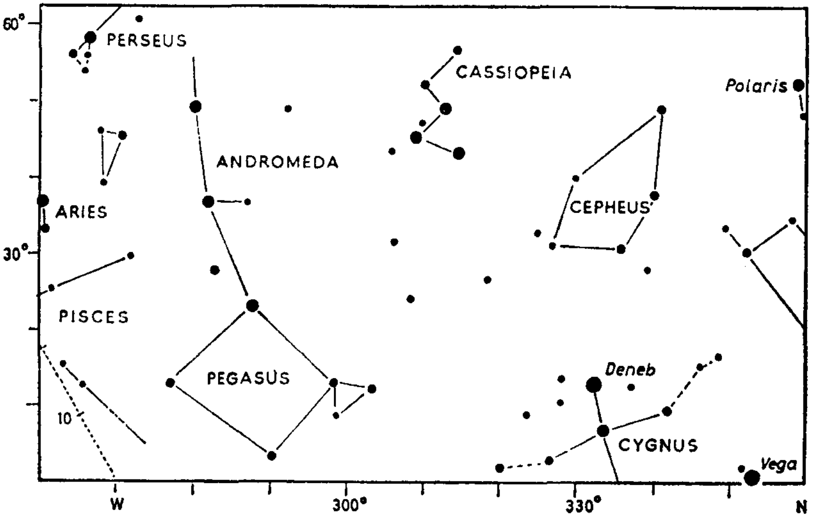
The broken line leading from the north (on the Northern Charts) or from the south (on the Southern Charts) is numbered to indicate the corresponding main chart. Thus on page 40 the N-S line numbered 6 is to be regarded as an extension of the centre (south) line of chart 6 on pages 26 and 27, and at the top of these pages are printed the dates and times which are appropriate. Similarly, on page 67, the S-N line numbered 10 connects with the north line of the upper charts on page 60.

The overhead stars are plotted as maps on a conical projection, and the scale is rather smaller than that of the main charts.

1L

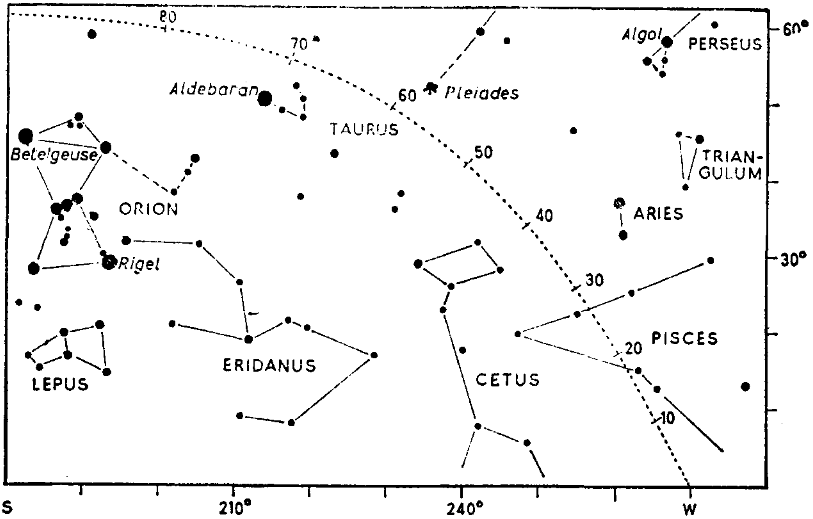
October 6 at 5^h	October 21 at 4^h
November 6 at 3^h	November 21 at 2^h
December 6 at 1^h	December 21 at midnight
January 6 at 23^h	January 21 at 22^h
February 6 at 21^h	February 21 at 20^h

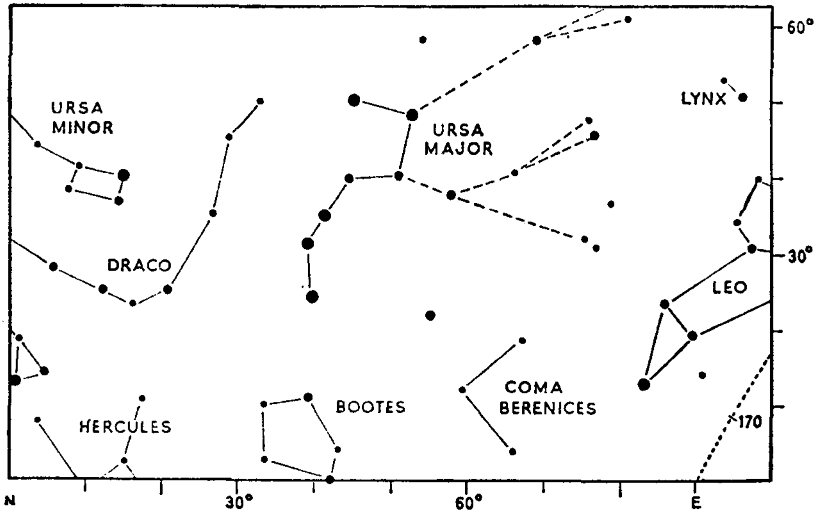




October 6 at 5^h	October 21 at 4^h
November 6 at 3^h	November 21 at 2^h
December 6 at 1^h	December 21 at midnight
January 6 at 23^h	January 21 at 22^h
February 6 at 21^h	February 21 at 20^h

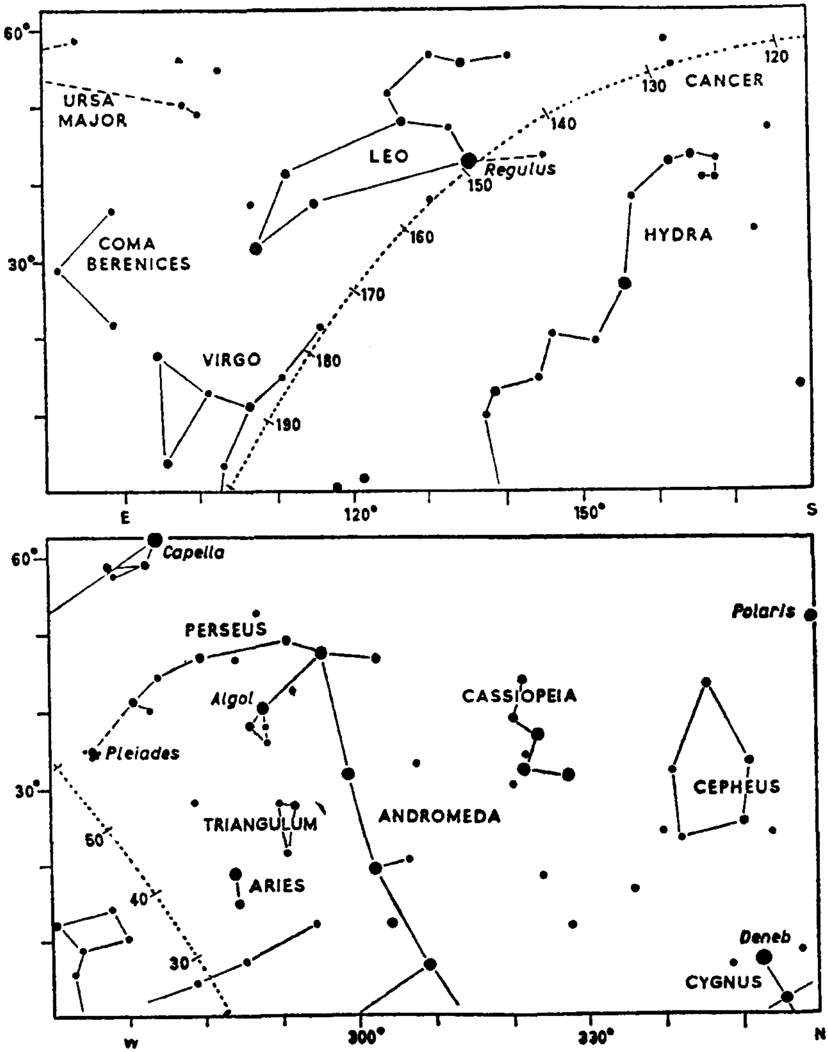
1R





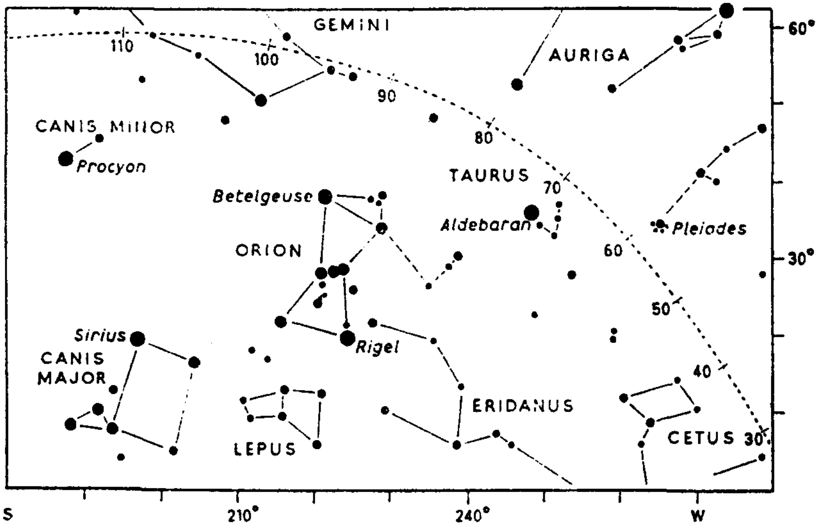
2L

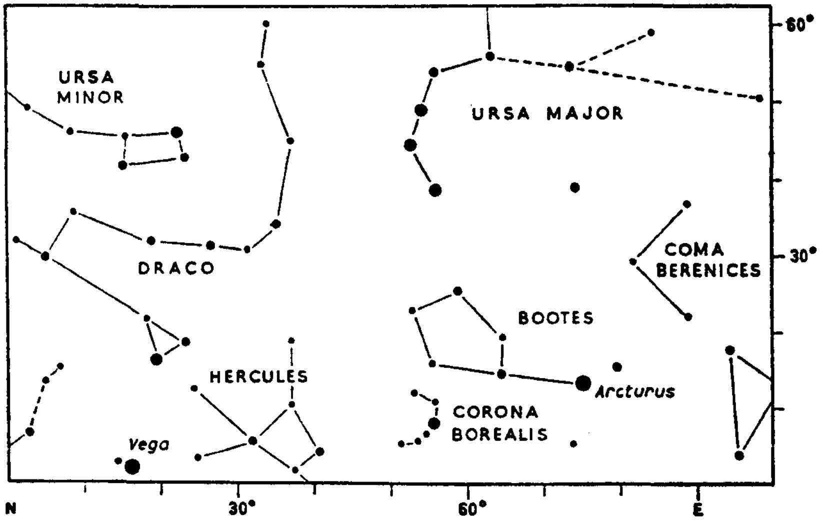
November 6 at	5^h	November 21 at	4^h
December 6 at	3^h	December 21 at	2^h
January 6 at	1^h	January 21 at	midnight
February 6 at	23^h	February 21 at	22^h
March 6 at	21^h	March 21 at	20^h



November 6 at 5^h	November 21 at 4^h
December 6 at 3^h	December 21 at 2^h
January 6 at 1^h	January 21 at midnight
February 6 at 23^h	February 21 at 22^h
March 6 at 21^h	March 21 at 20^h

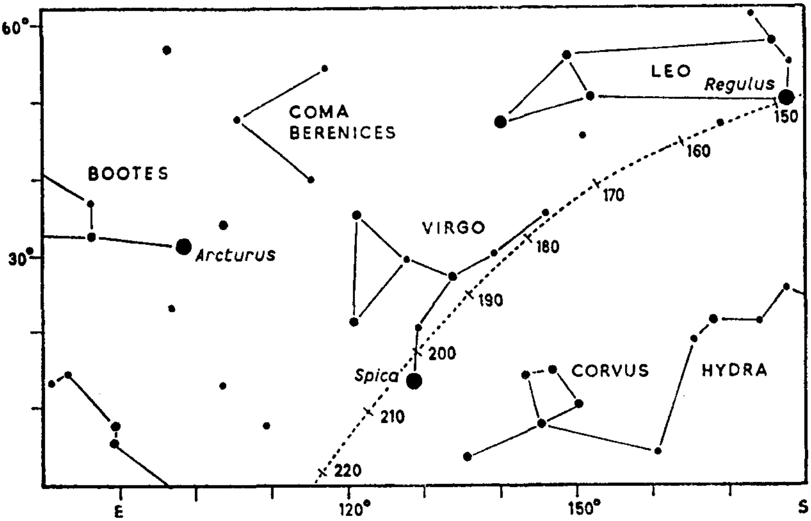
2R

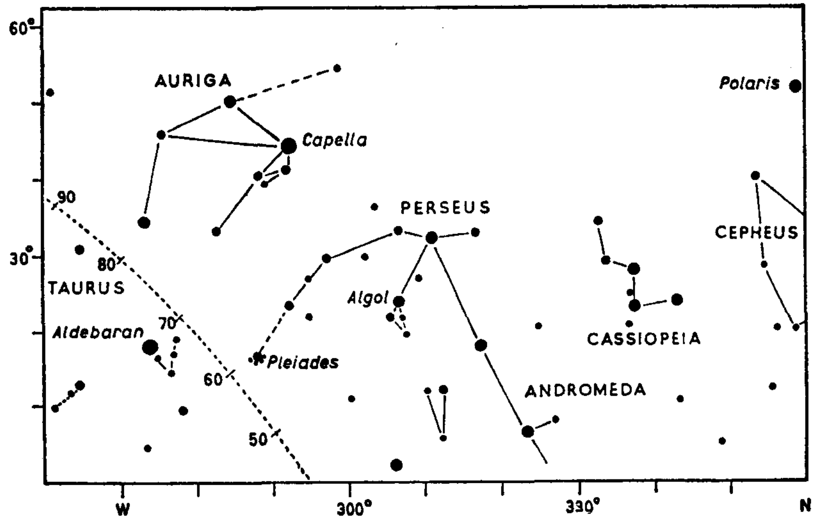




3L

December 6 at 5^h	December 21 at 4^h
January 6 at 3^h	January 21 at 2^h
February 6 at 1^h	February 21 at midnight
March 6 at 23^h	March 21 at 22^h
April 6 at 21^h	April 21 at 20^h

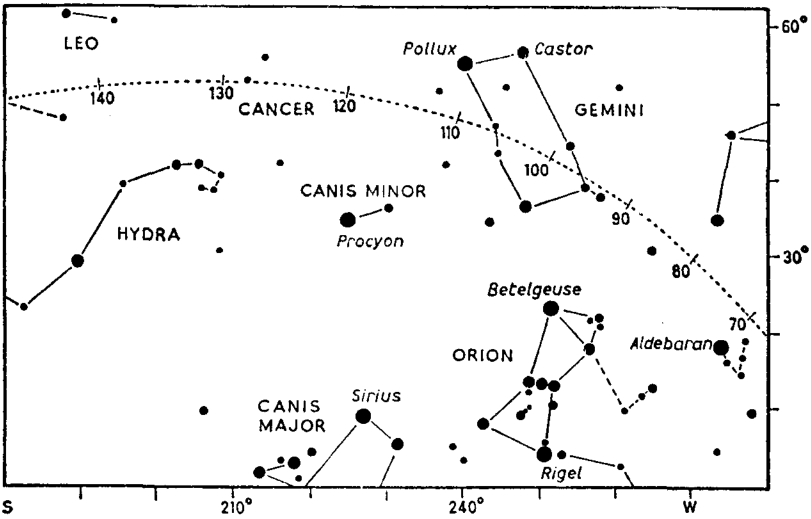


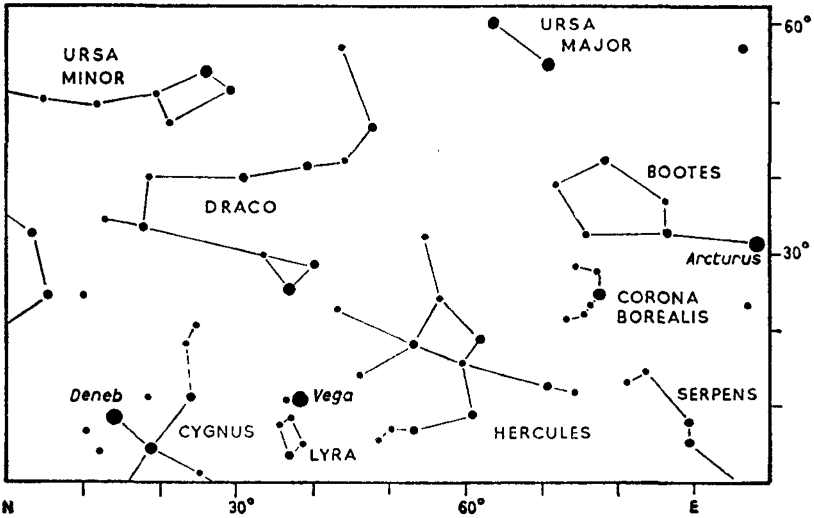


December 6 at 5^h
January 6 at 3^h
February 6 at 1^h
March 6 at 23^h
April 6 at 21^h

December 21 at 4^h
January 21 at 2^h
February 21 at midnight
March 21 at 22^h
April 21 at 20^h

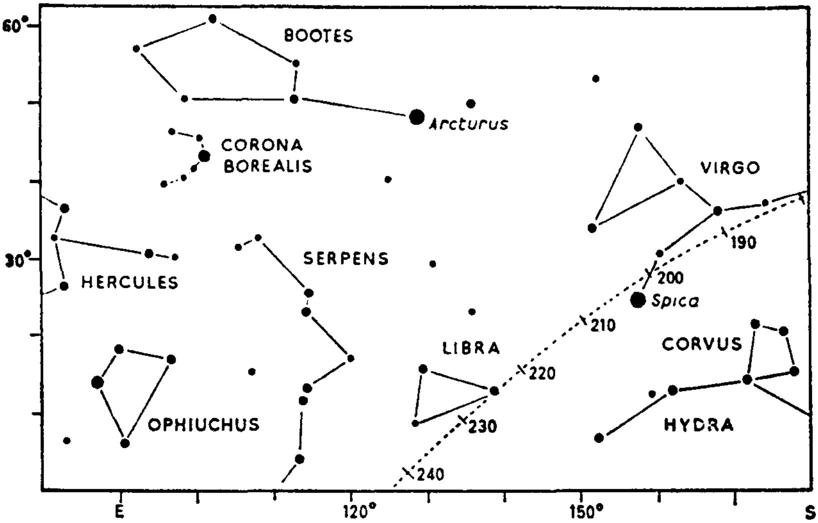
3R

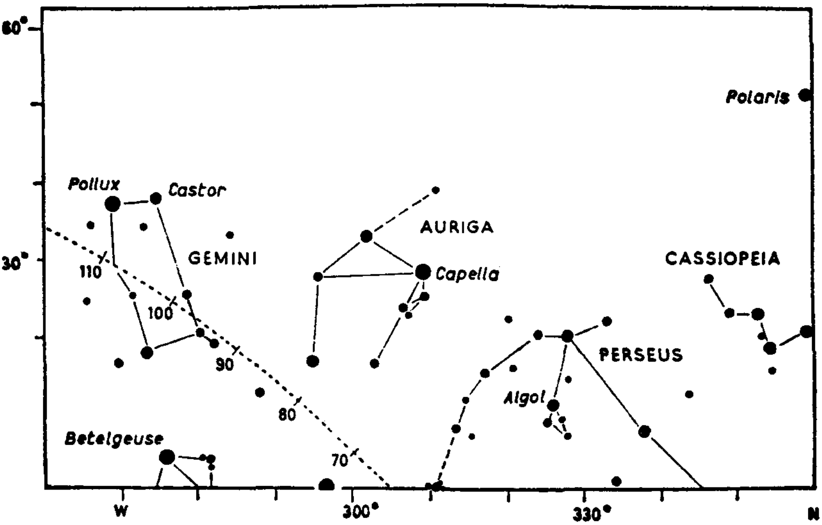




4L

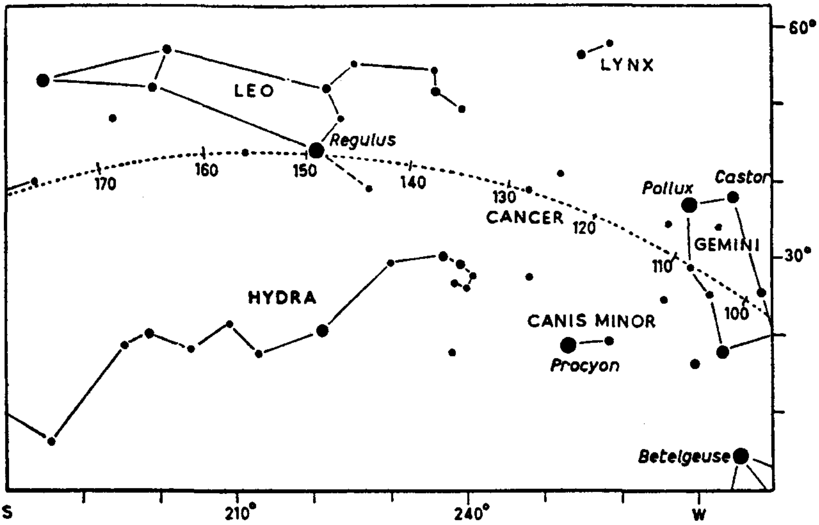
January 6 at 5h	January 21 at 4h
February 6 at 3h	February 21 at 2h
March 6 at 1h	March 21 at midnight
April 6 at 23h	April 21 at 22h
May 6 at 21h	May 21 at 20h

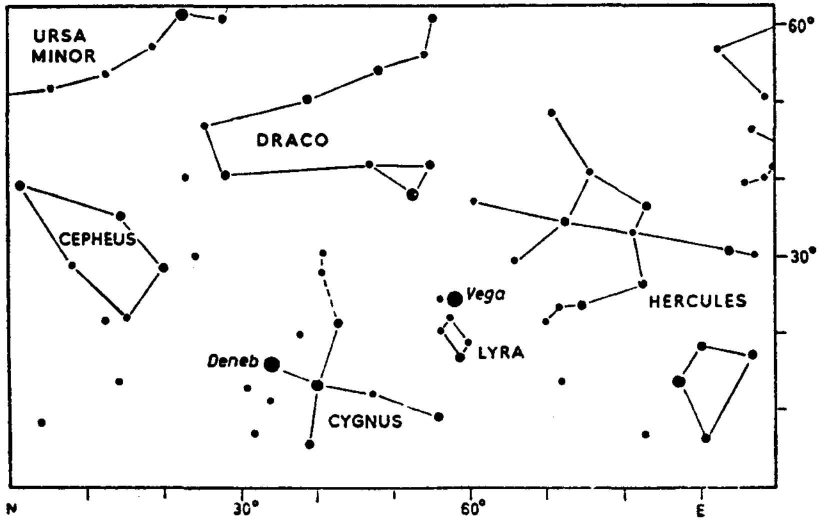




January 6 at 5^h	January 21 at 4^h
February 6 at 3^h	February 21 at 2^h
March 6 at 1^h	March 21 at midnight
April 6 at 23^h	April 21 at 22^h
May 6 at 21^h	May 21 at 20^h

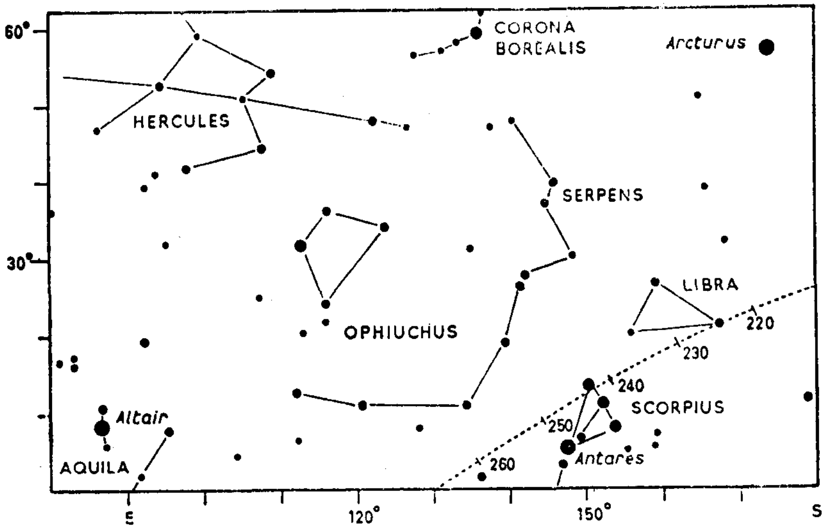
4R

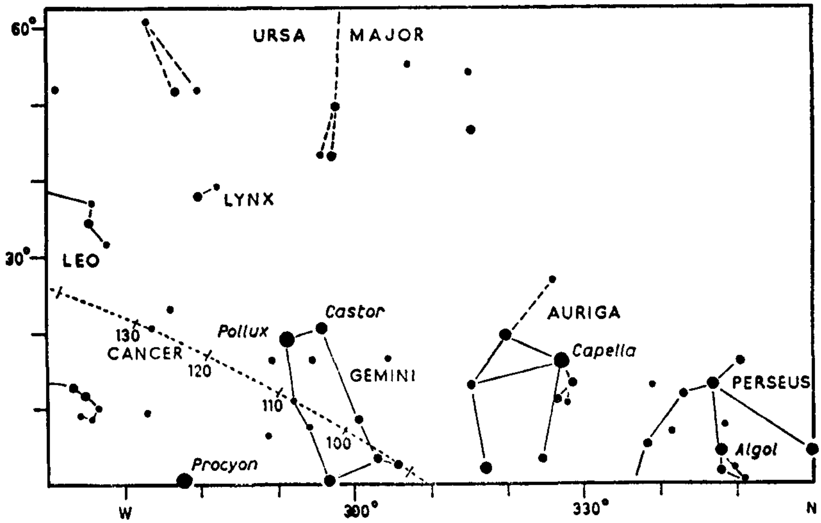




5L

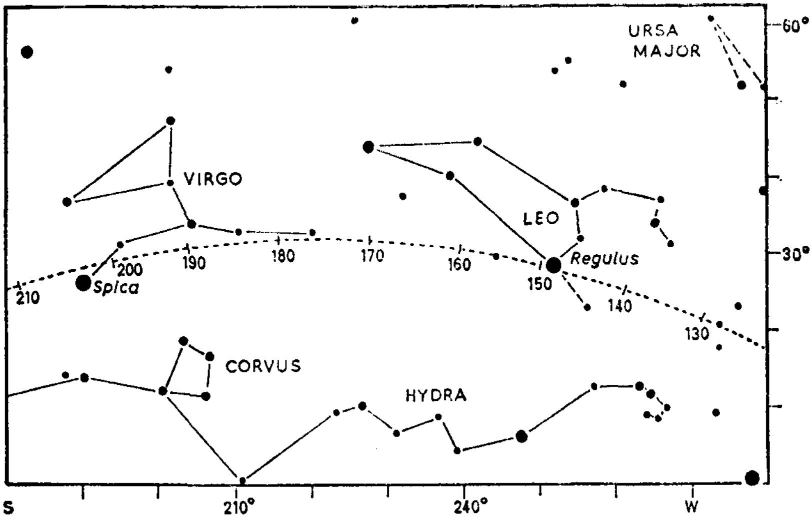
January 6 at 7h	January 21 at 6h
February 6 at 5h	February 21 at 4h
March 6 at 3h	March 21 at 2h
April 6 at 1h	April 21 at midnight
May 6 at 23h	May 21 at 22h

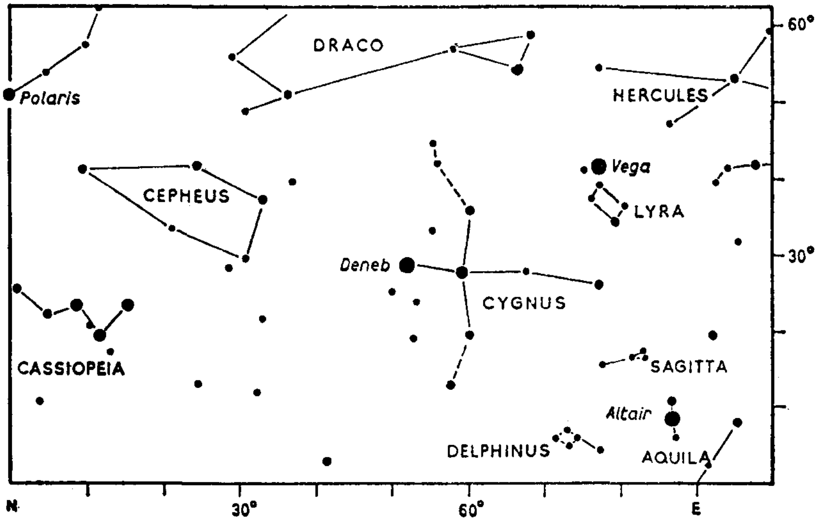




January 6 at 7^h	January 21 at 6^h
February 6 at 5^h	February 21 at 4^h
March 6 at 3^h	March 21 at 2^h
April 6 at 1^h	April 21 at midnight
May 6 at 23^h	May 21 at 22^h

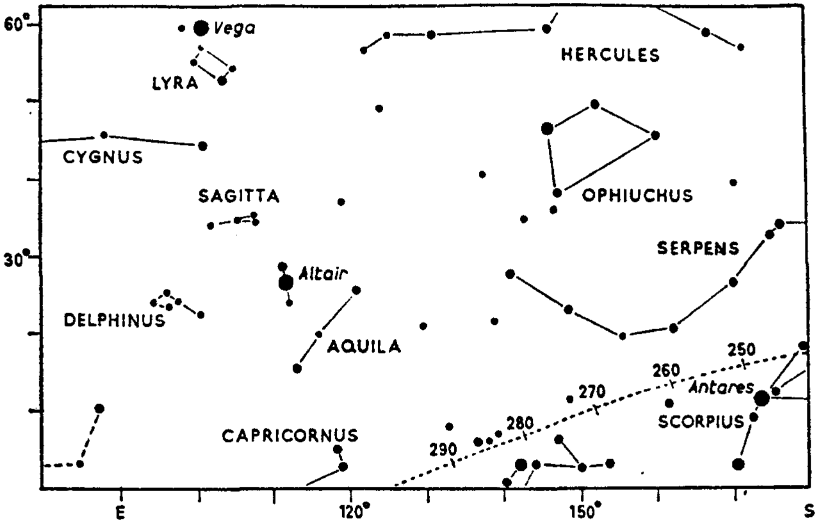
5R

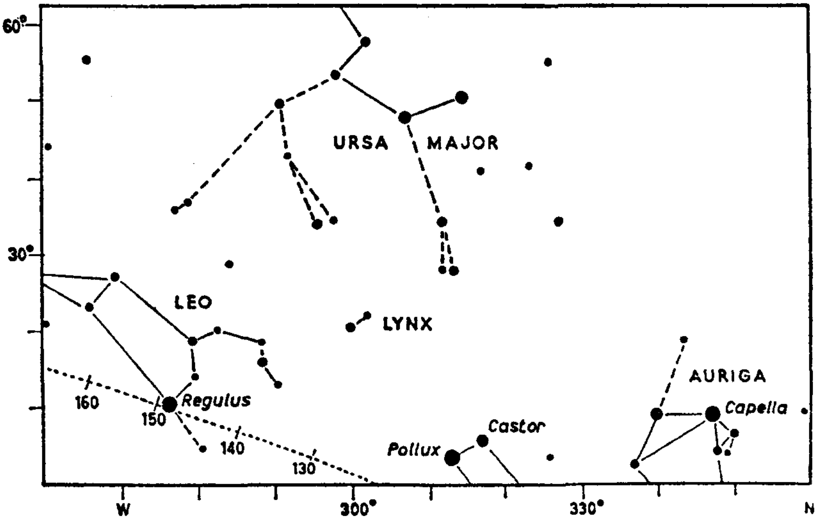




6L

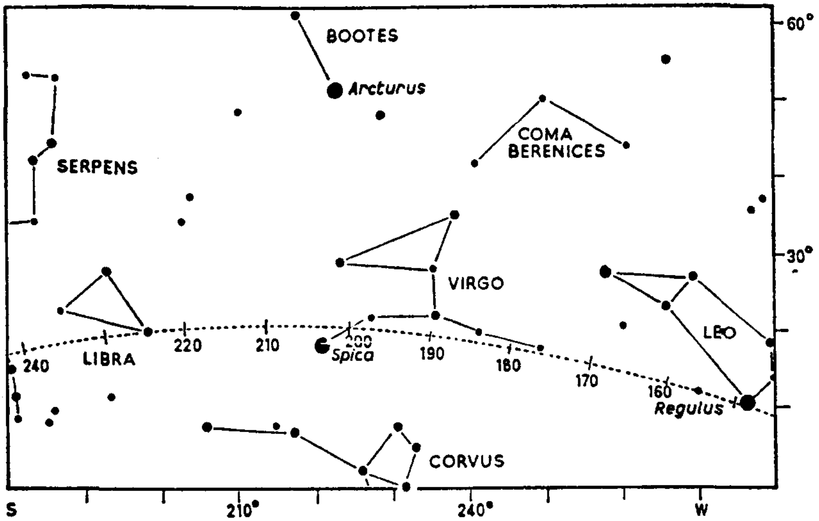
March 6 at 5^h	March 21 at 4^h
April 6 at 3^h	April 21 at 2^h
May 6 at 1^h	May 21 at midnight
June 6 at 23^h	June 21 at 22^h
July 6 at 21^h	July 21 at 20^h

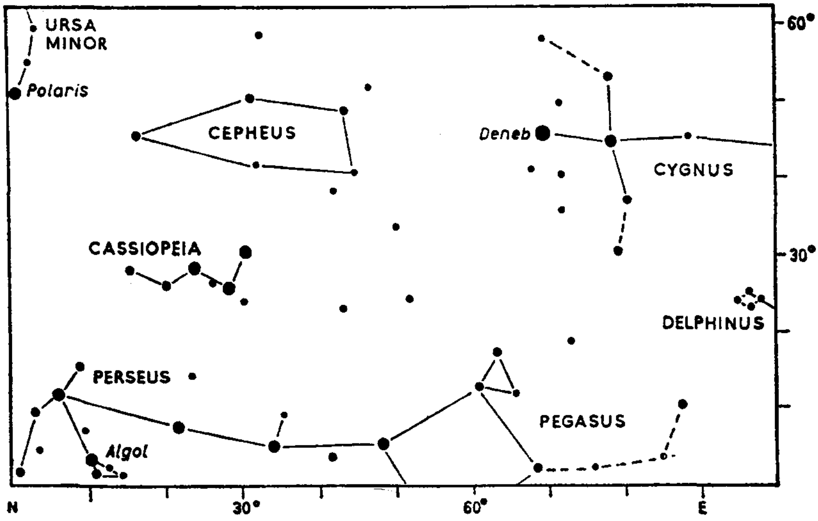




March 6 at 5^h	March 21 at 4^h
April 6 at 3^h	April 21 at 2^h
May 6 at 1^h	May 21 at midnight
June 6 at 23^h	June 21 at 22^h
July 6 at 21^h	July 21 at 20^h

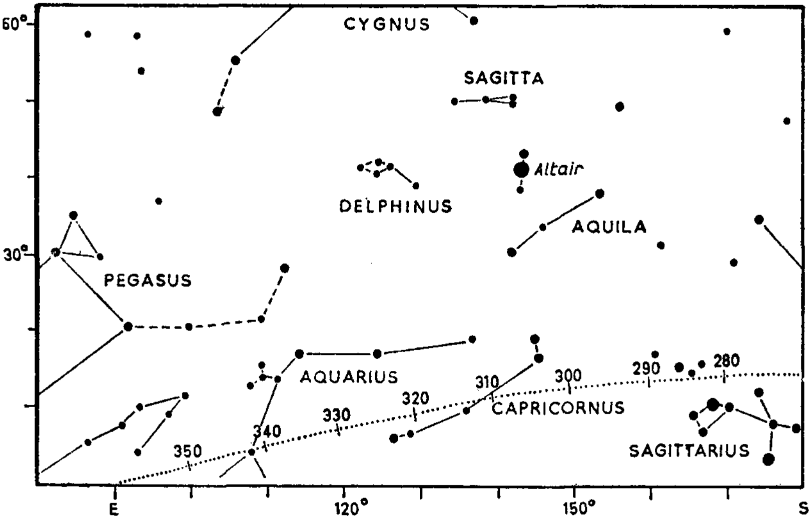
6R

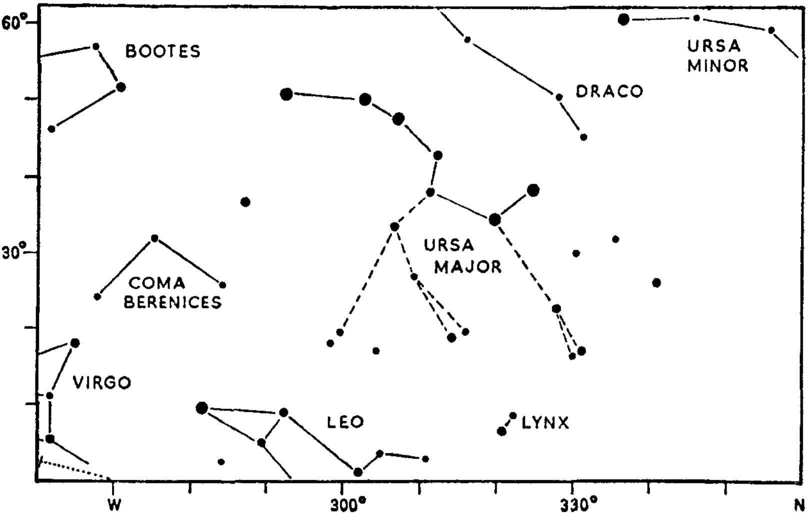




7L

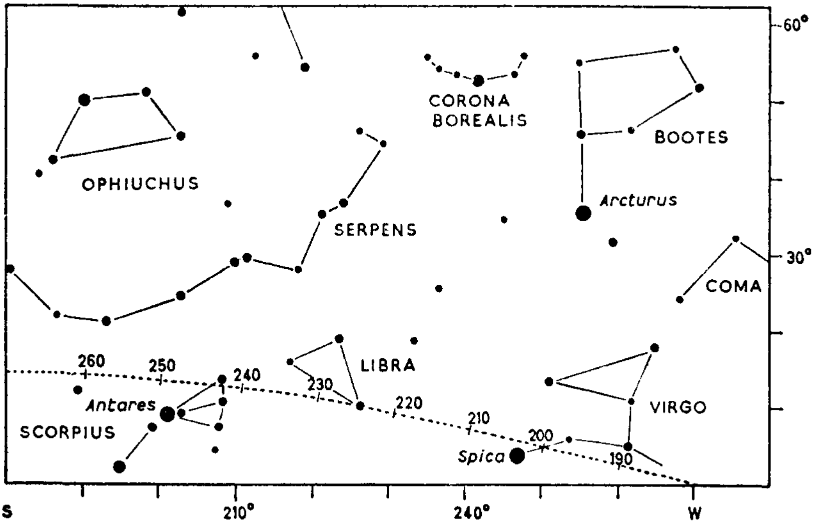
May 6 at 3ʰ	May 21 at 2ʰ
June 6 at 1ʰ	June 21 at midnight
July 6 at 23ʰ	July 21 at 22ʰ
August 6 at 21ʰ	August 21 at 20ʰ
September 6 at 19ʰ	September 21 at 18ʰ

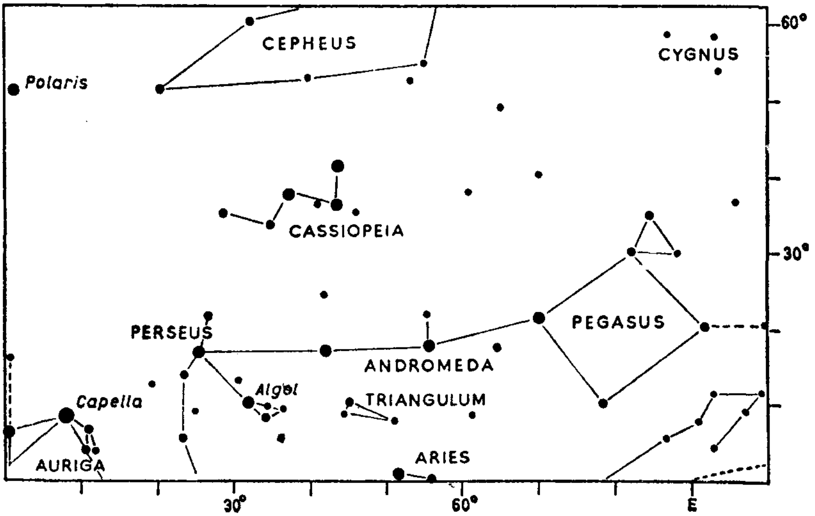




May 6 at 3^h	May 21 at 2^h
June 6 at 1^h	June 21 at midnight
July 6 at 23^h	July 21 at 22^h
August 6 at 21^h	August 21 at 20^h
September 6 at 19^h	September 21 at 18^h

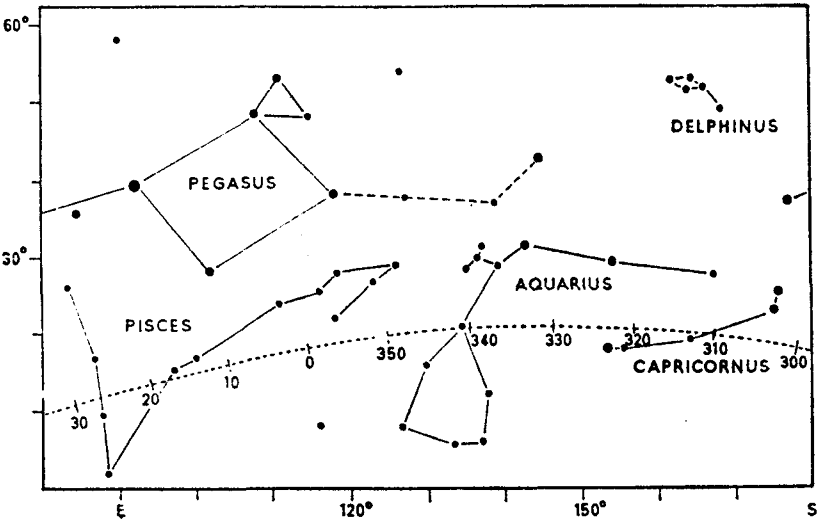
7R

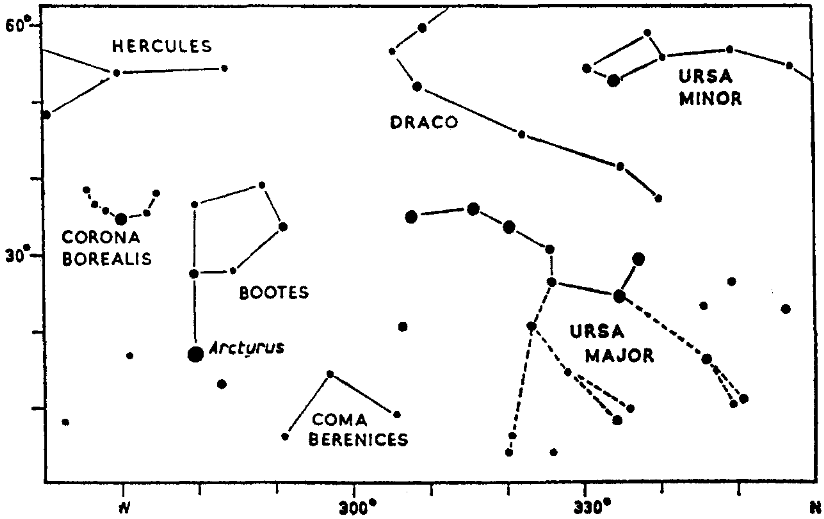




8L

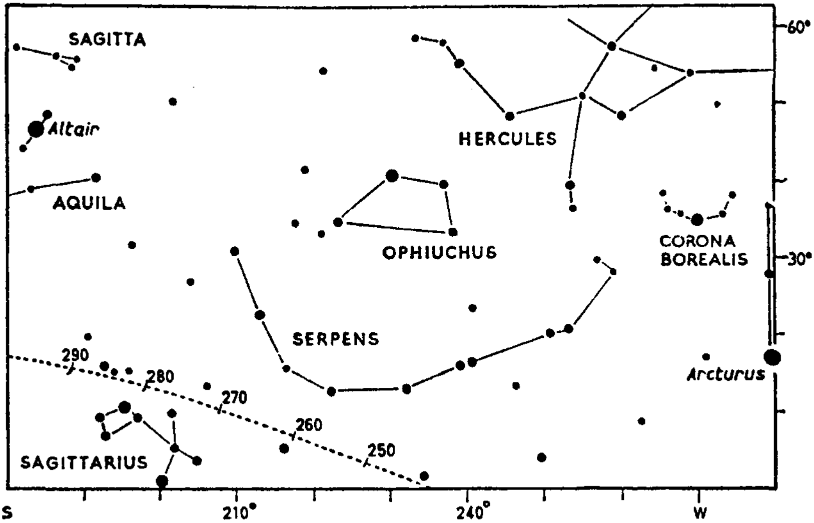
July 6 at 1^h^	July 21 at midnight
August 6 at 23^h^	August 21 at 22^h^
September 6 at 21^h^	September 21 at 20^h^
October 6 at 19^h^	October 21 at 18^h^
November 6 at 17^h^	November 21 at 16^h^

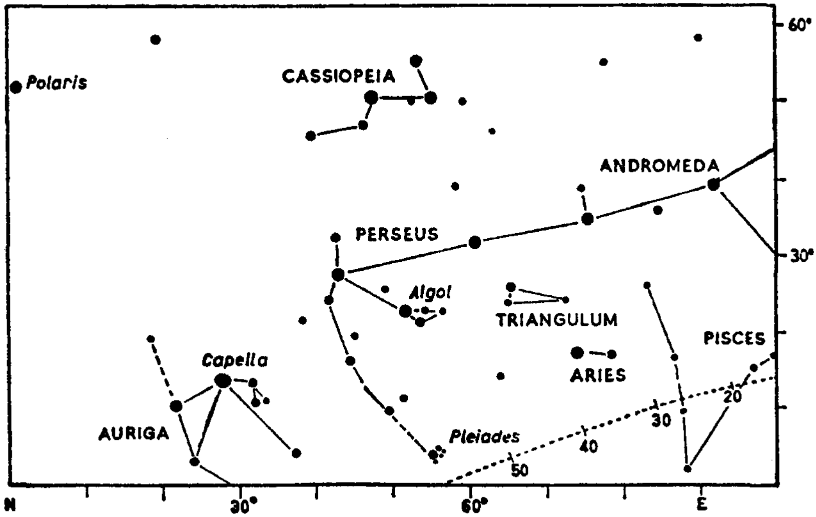




July 6 at 1ʰ	July 21 at midnight
August 6 at 23ʰ	August 21 at 22ʰ
September 6 at 21ʰ	September 21 at 20ʰ
October 6 at 19ʰ	October 21 at 18ʰ
November 6 at 17ʰ	November 21 at 16ʰ

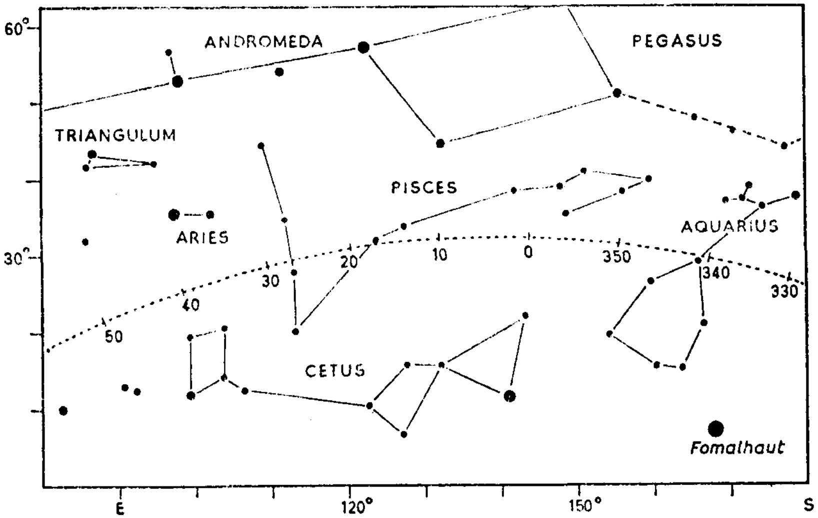
8R

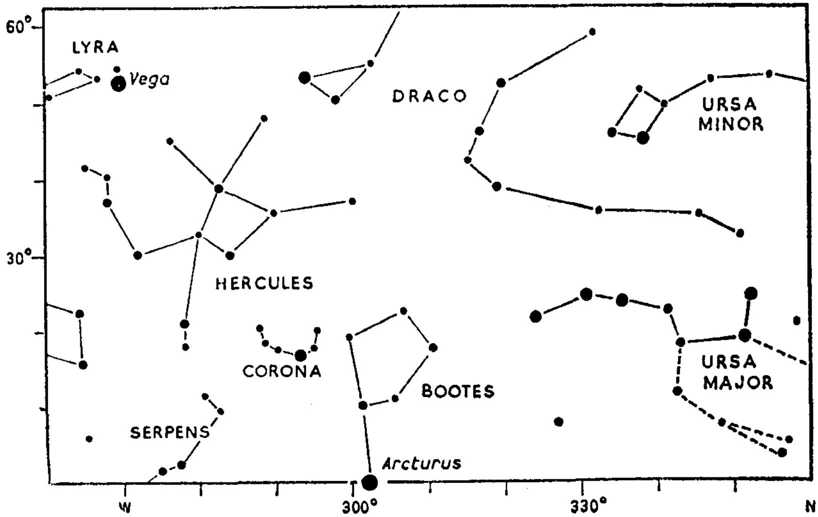




9L

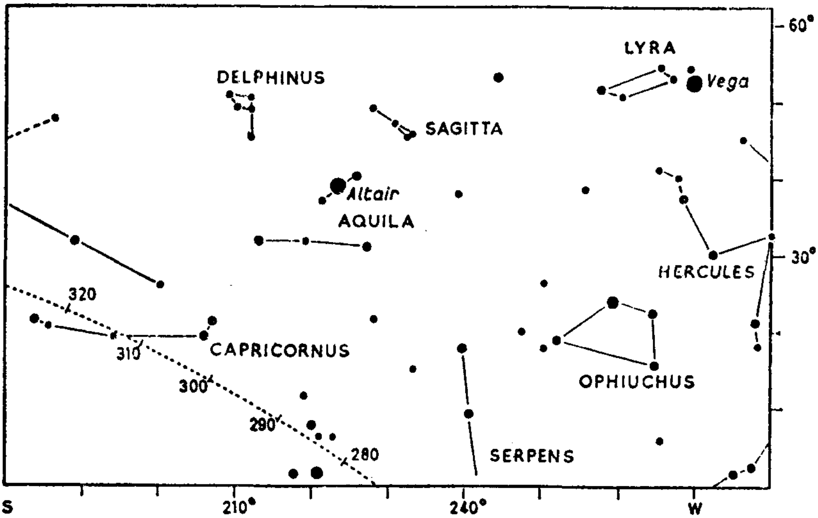
August 6 at 1^{h}	August 21 at midnight
September 6 at 23^{h}	September 21 at 22^{h}
October 6 at 21^{h}	October 21 at 20^{h}
November 6 at 19^{h}	November 21 at 18^{h}
December 6 at 17^{h}	December 21 at 16^{h}

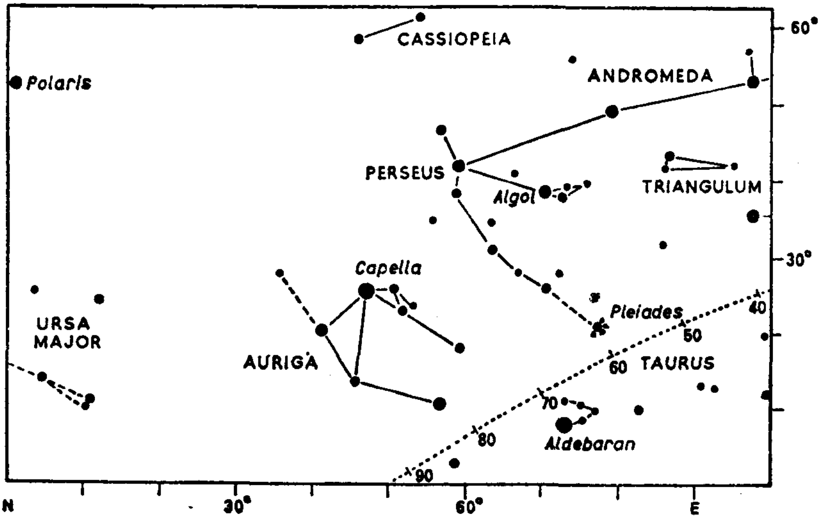




August 6 at 1^h	August 21 at midnight
September 6 at 23^h	September 21 at 22^h
October 6 at 21^h	October 21 at 20^h
November 6 at 19^h	November 21 at 18^h
December 6 at 17^h	December 21 at 16^h

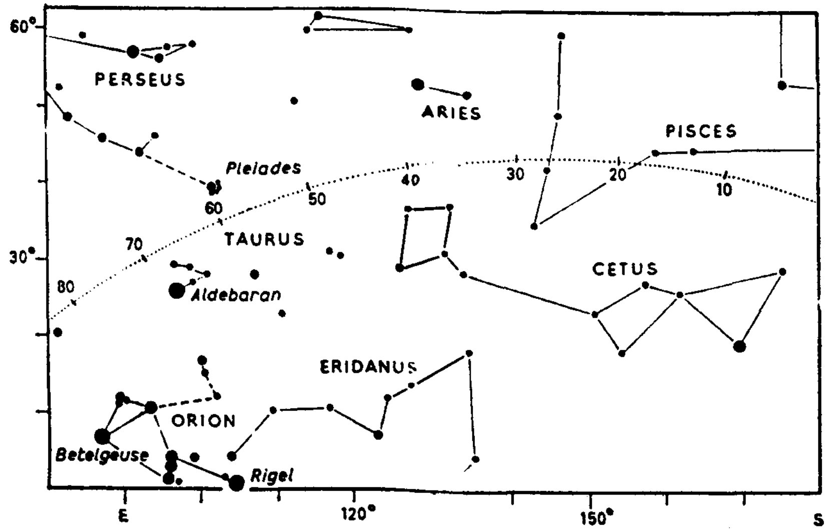
9R

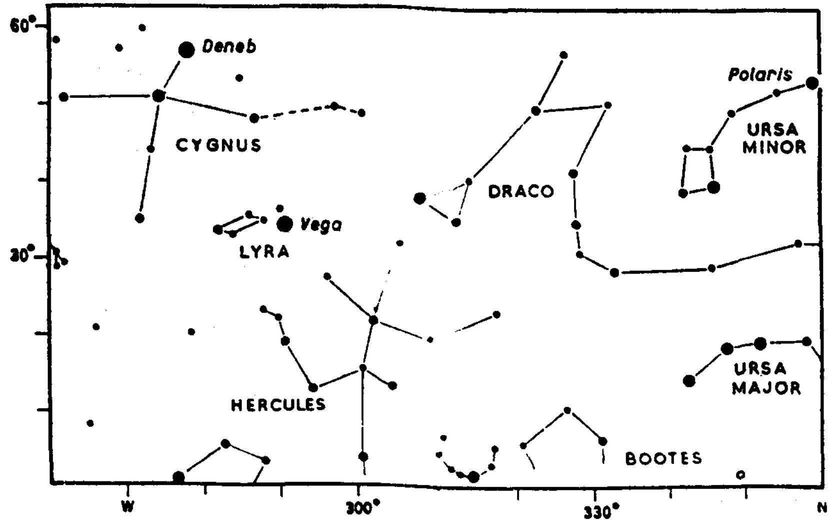




10L

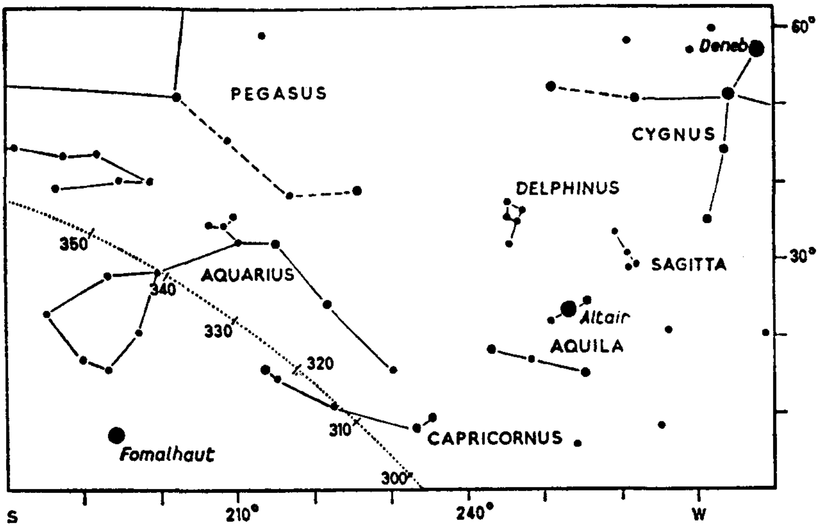
August 6 at 3^h	August 21 at 2^h
September 6 at 1^h	September 21 at midnight
October 6 at 23^h	October 21 at 22^h
November 6 at 21^h	November 21 at 20^h
December 6 at 19^h	December 21 at 18^h

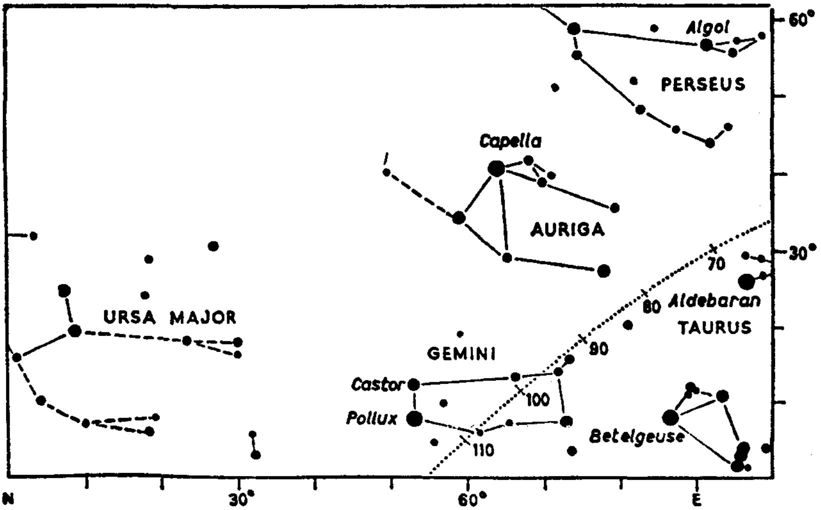




August 6 at 3^h August 21 at 2^h
September 6 at 1^h September 21 at midnight
October 6 at 23^h October 21 at 22^h
November 6 at 21^h November 21 at 20^h
December 6 at 19^h December 21 at 18^h

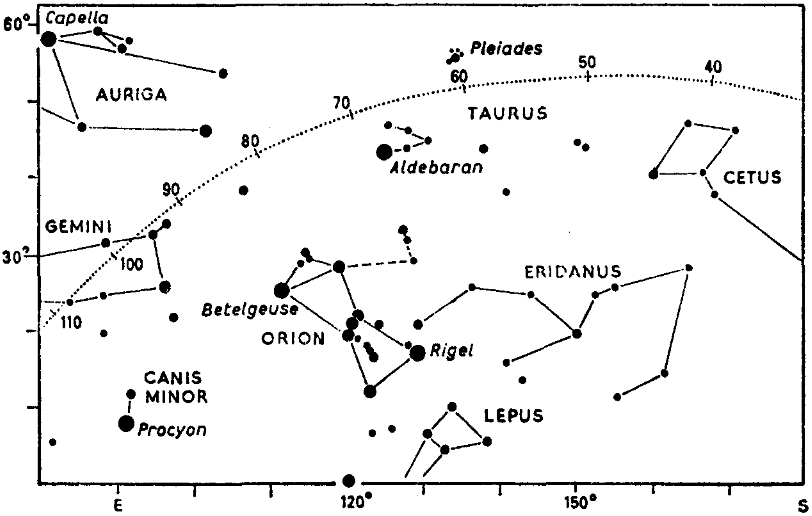
10R

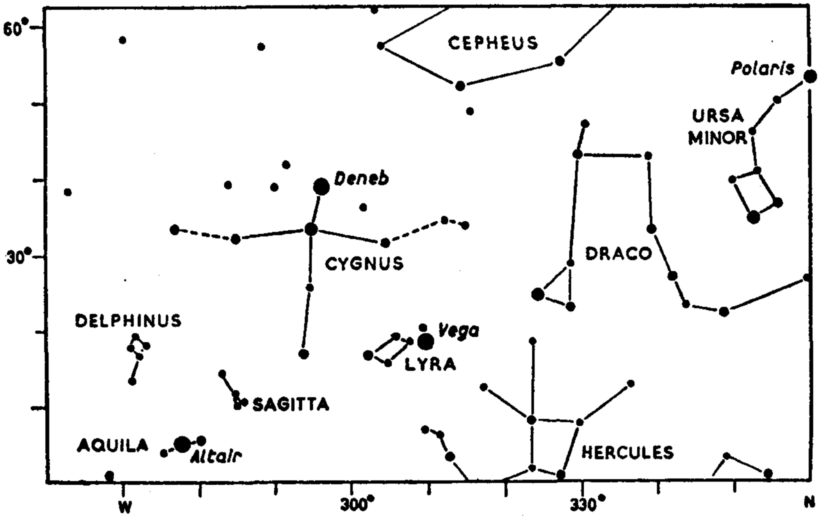




11L

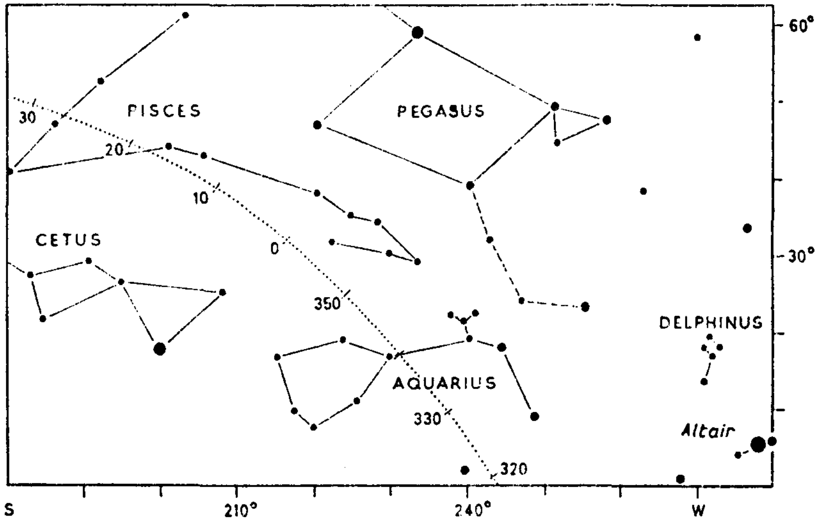
September 6 at 3^h	September 21 at 2^h
October 6 at 1^h	October 21 at midnight
November 6 at 23^h	November 21 at 22^h
December 6 at 21^h	December 21 at 20^h
January 6 at 19^h	January 21 at 18^h

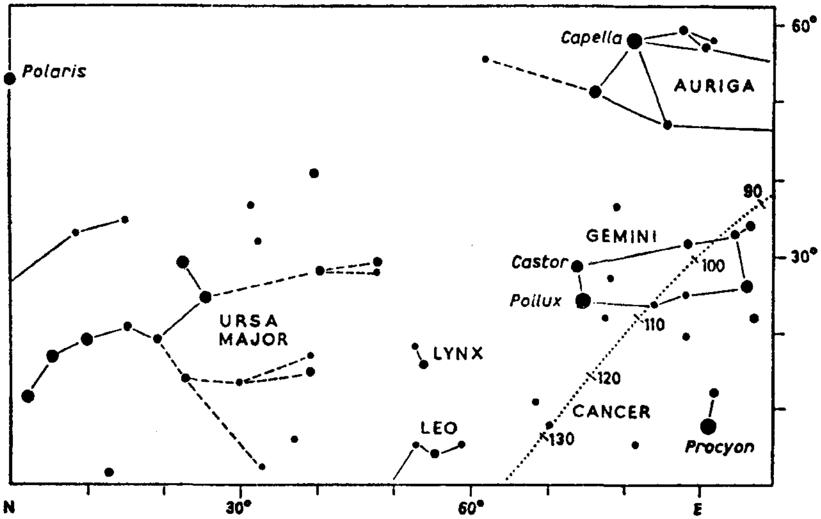




11R

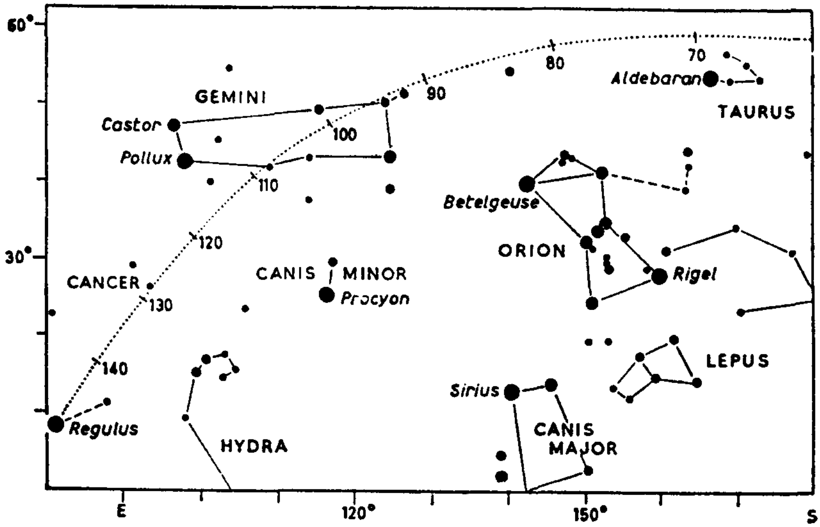
September 6 at 3^{h}	September 21 at 2^{h}
October 6 at 1^{h}	October 21 at midnight
November 6 at 23^{h}	November 21 at 22^{h}
December 6 at 21^{h}	December 21 at 20^{h}
January 6 at 19^{h}	January 21 at 18^{h}

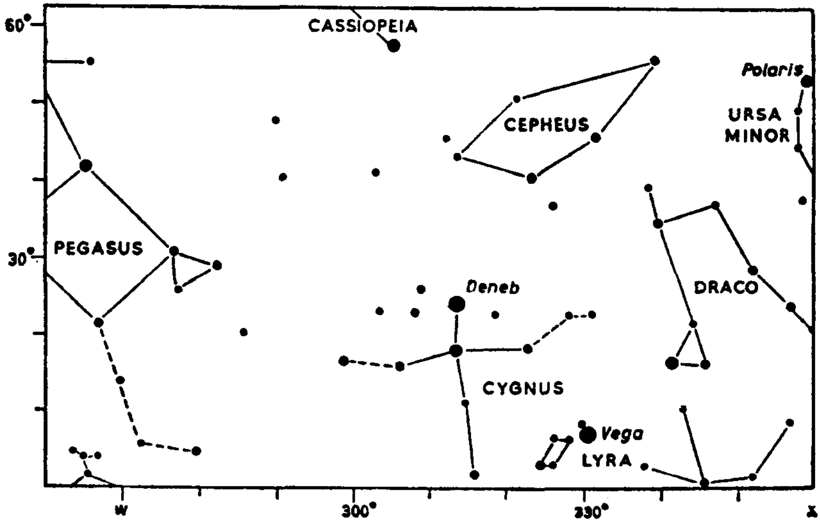




12L

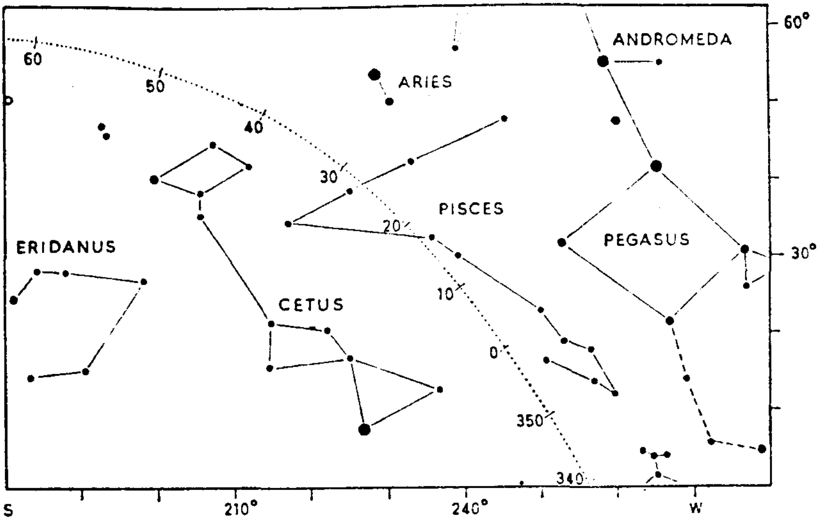
October 6 at 3^h	October 21 at 2^h
November 6 at 1^h	November 21 at midnight
December 6 at 23^h	December 21 at 22^h
January 6 at 21^h	January 21 at 20^h
February 6 at 19^h	February 21 at 18^h

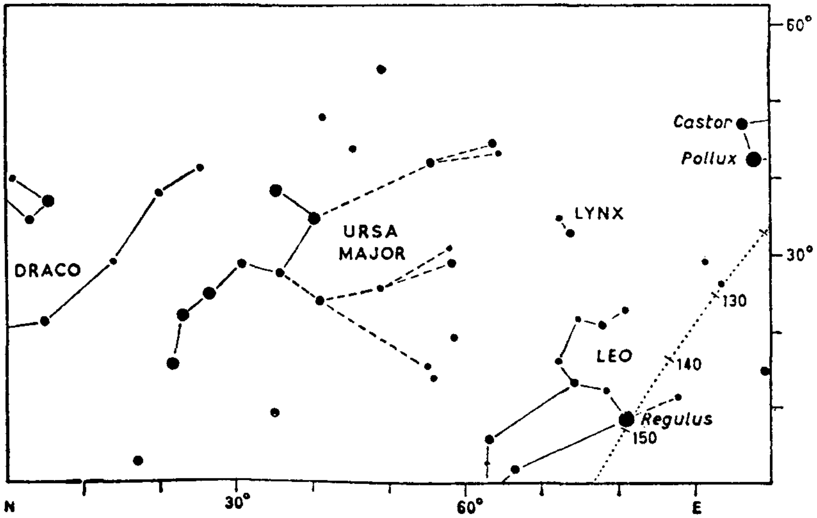


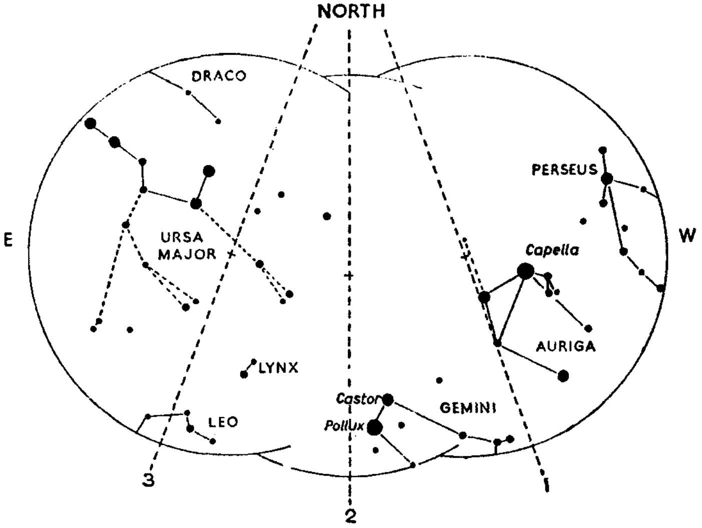


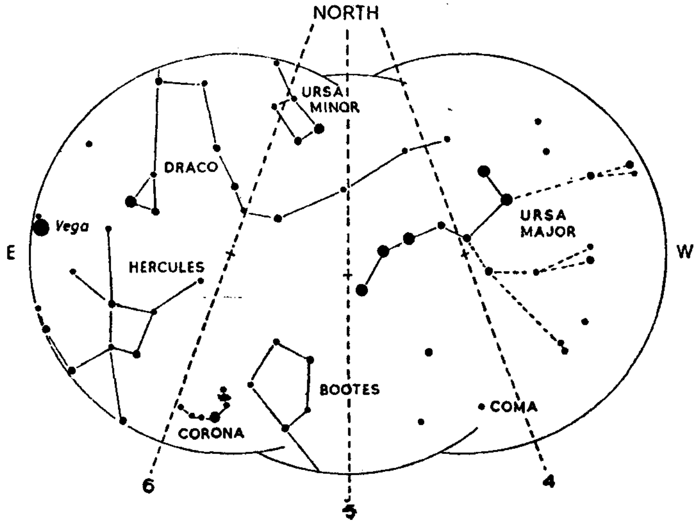
October 6 at 3^h	October 21 at 2^h
November 6 at 1^h	November 21 at midnight
December 6 at 23^h	December 21 at 22^h
January 6 at 21^h	January 21 at 20^h
February 6 at 19^h	February 21 at 18^h

12R

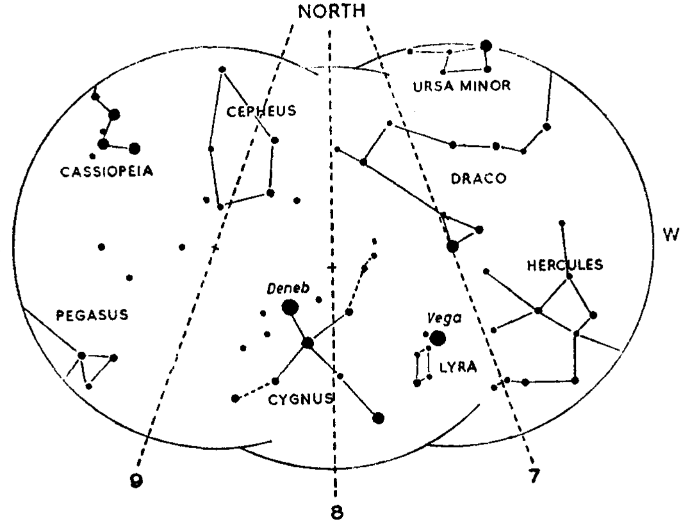


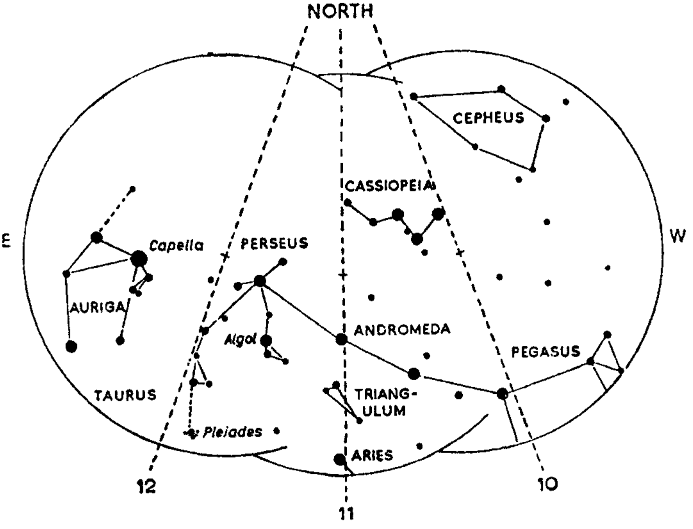






Northern Hemisphere Overhead Stars

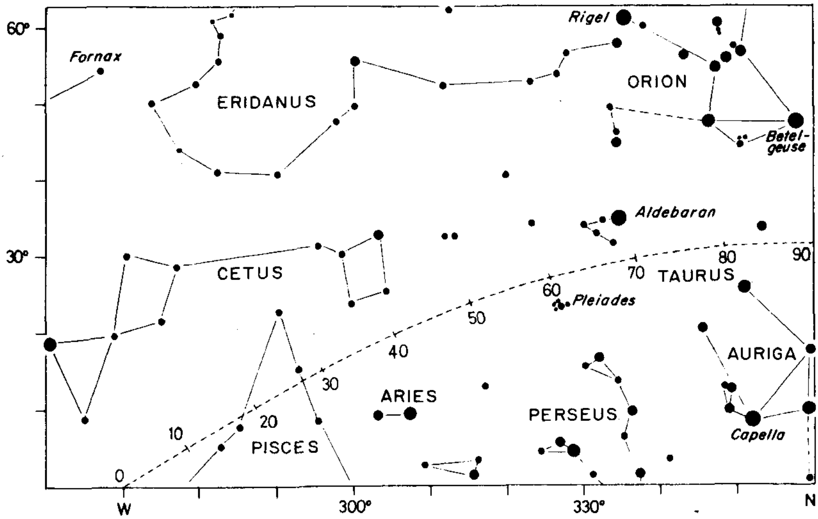


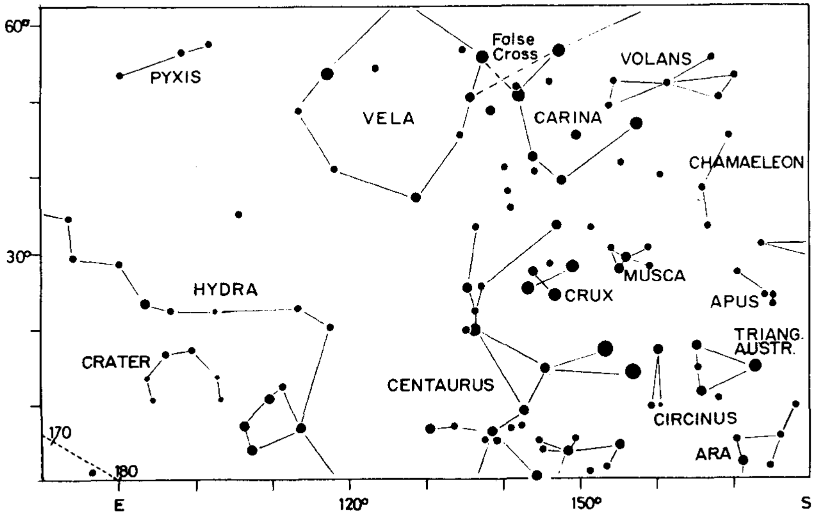


Northern Hemisphere Overhead Stars

1L

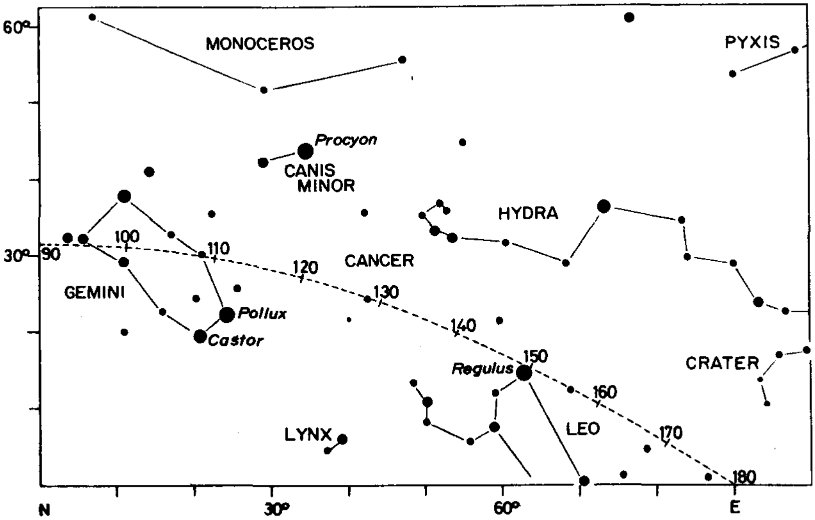
October 6 at 5ʰ	October 21 at 4ʰ
November 6 at 3ʰ	November 21 at 2ʰ
December 6 at 1ʰ	December 21 at midnight
January 6 at 23ʰ	January 21 at 22ʰ
February 6 at 21ʰ	February 21 at 20ʰ

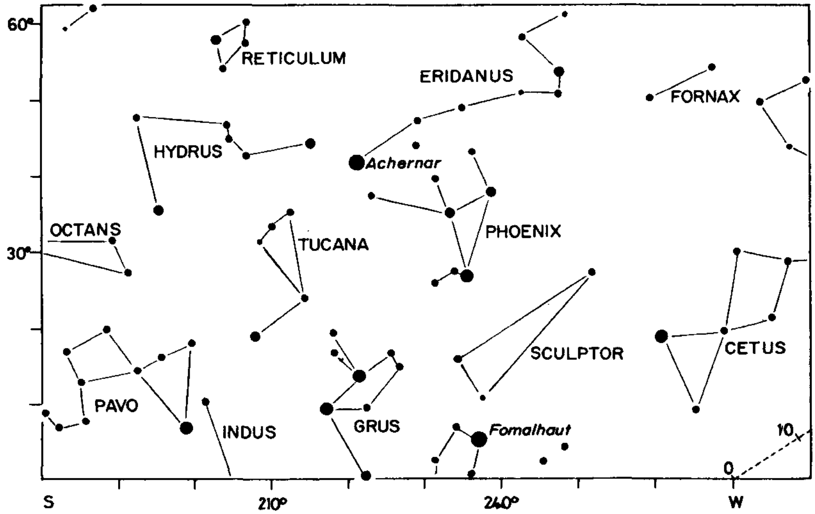




October 6 at 5^h	October 21 at 4^h
November 6 at 3^h	November 21 at 2^h
December 6 at 1^h	December 21 at midnight
January 6 at 23^h	January 21 at 22^h
February 6 at 21^h	February 21 at 20^h

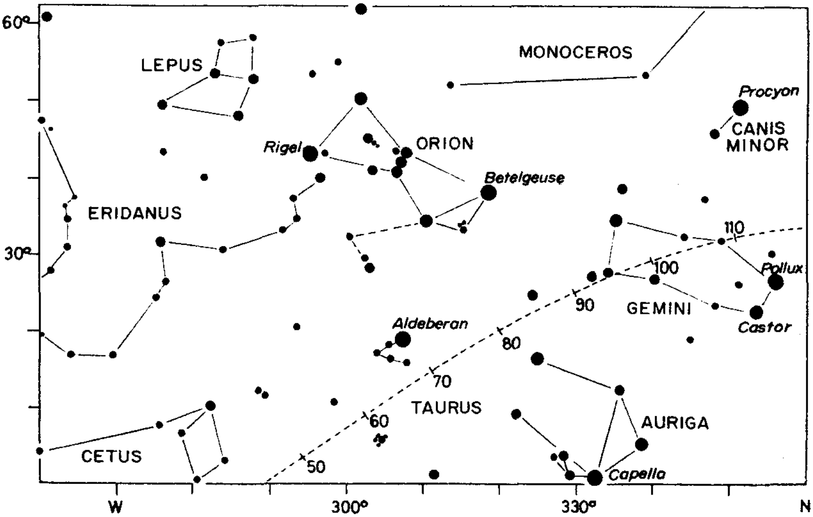
1R

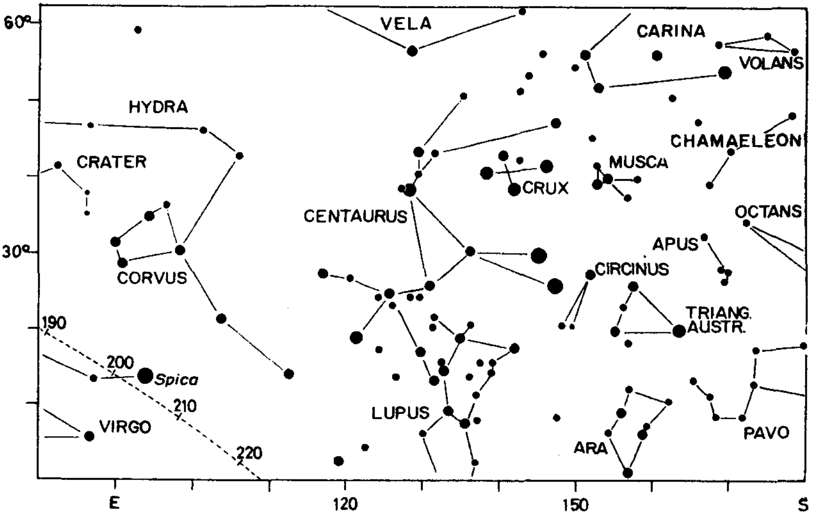




2L

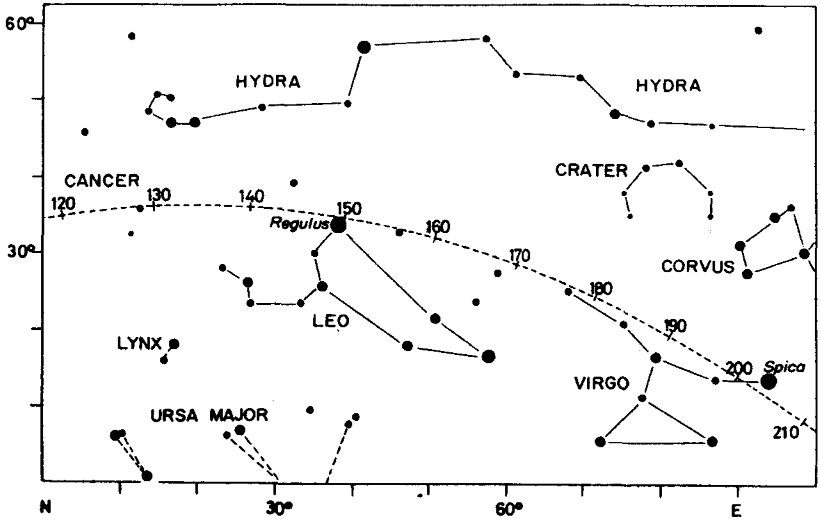
November 6 at 5^h November 21 at 4^h
December 6 at 3^h December 21 at 2^h
January 6 at 1^h January 21 at midnight
February 6 at 23^h February 21 at 22^h
March 6 at 21^h March 21 at 20^h

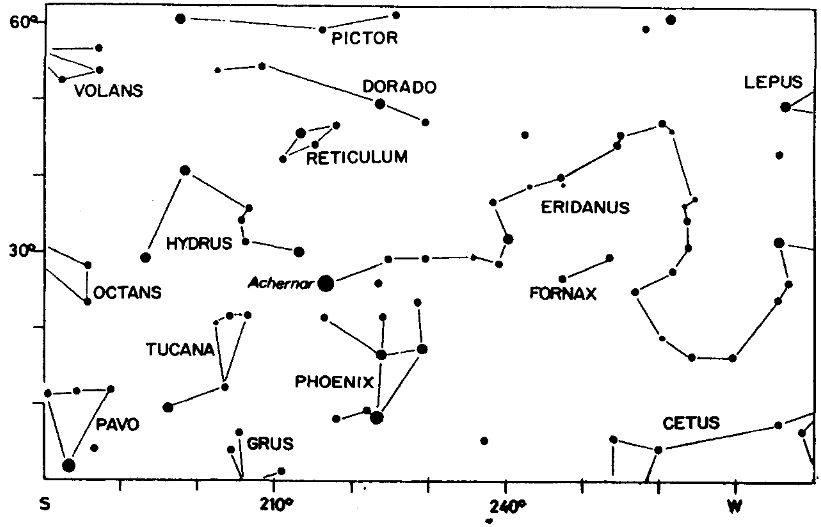




November 6 at 5h	November 21 at 4h
December 6 at 3h	December 21 at 2h
January 6 at 1h	January 21 at midnight
February 6 at 23h	February 21 at 22h
March 6 at 21h	March 21 at 20h

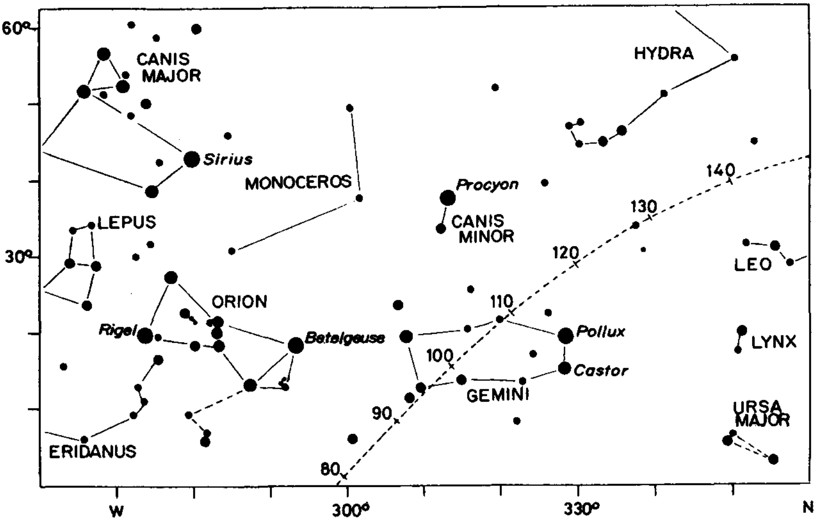
2R

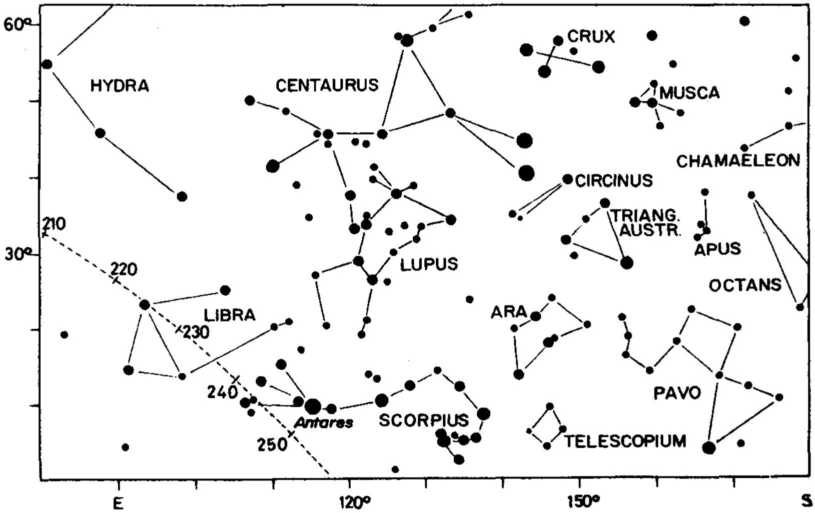




3L

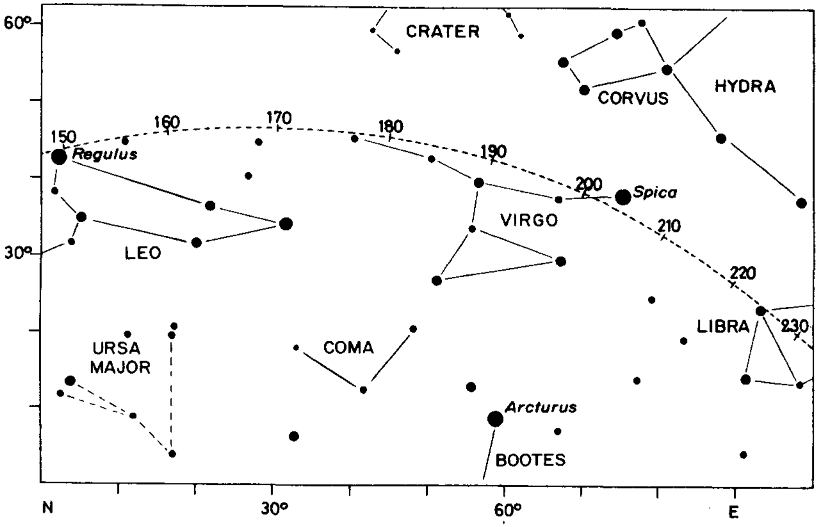
January 6 at 3^h	January 21 at 2^h
February 6 at 1^h	February 21 at midnight
March 6 at 23^h	March 21 at 22^h
April 6 at 21^h	April 21 at 20^h
May 6 at 19^h	May 21 at 18^h

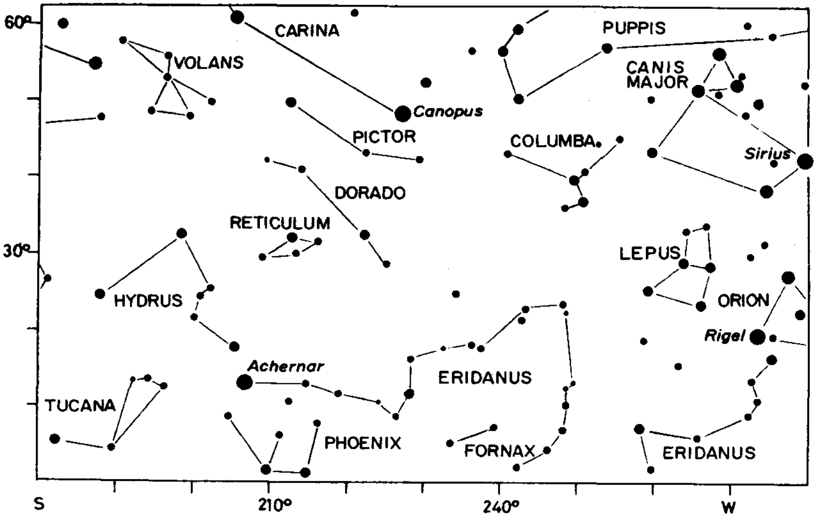




January 6 at 3^h	January 21 at 2^h
February 6 at 1^h	February 21 at midnight
March 6 at 23^h	March 21 at 22^h
April 6 at 21^h	April 21 at 20^h
May 6 at 19^h	May 21 at 18^h

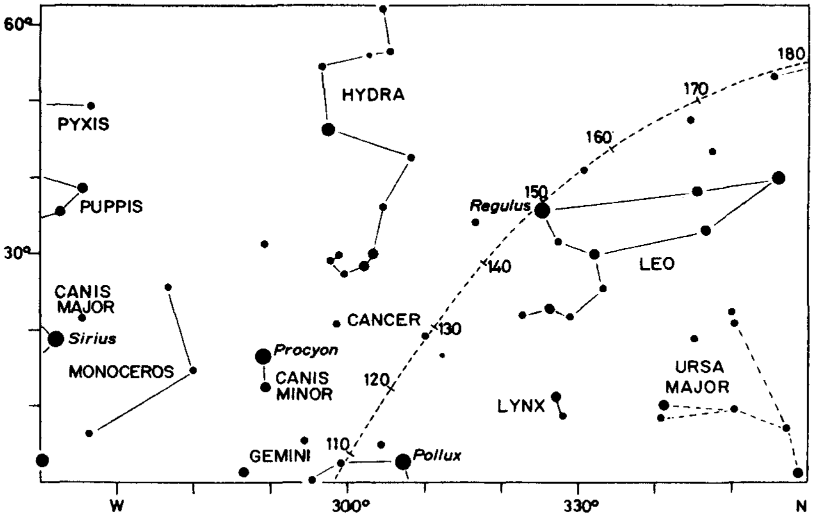
3R

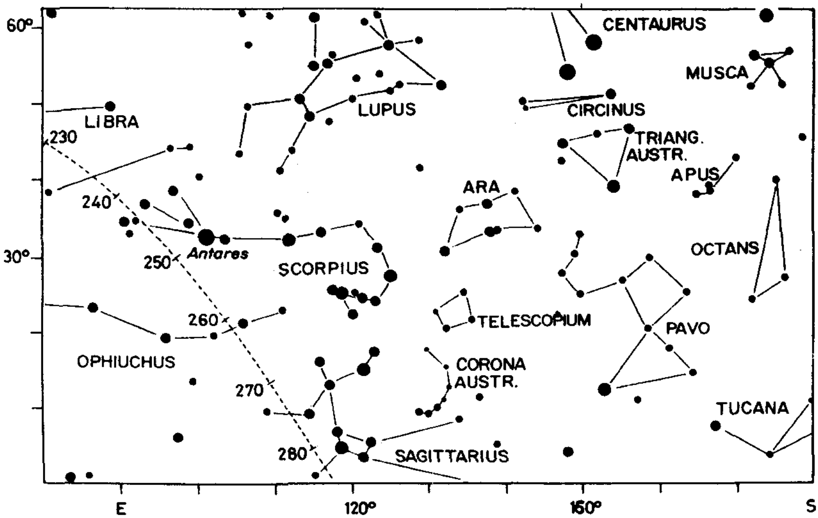




4L

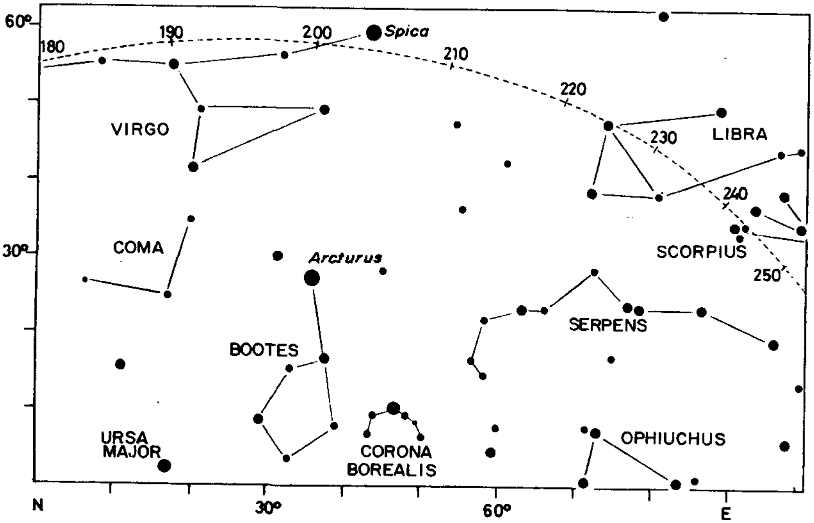
February 6 at 3h	February 21 at 2h
March 6 at 1h	March 21 at midnight
April 6 at 23h	April 21 at 22h
May 6 at 21h	May 21 at 20h
June 6 at 19h	June 21 at 18h

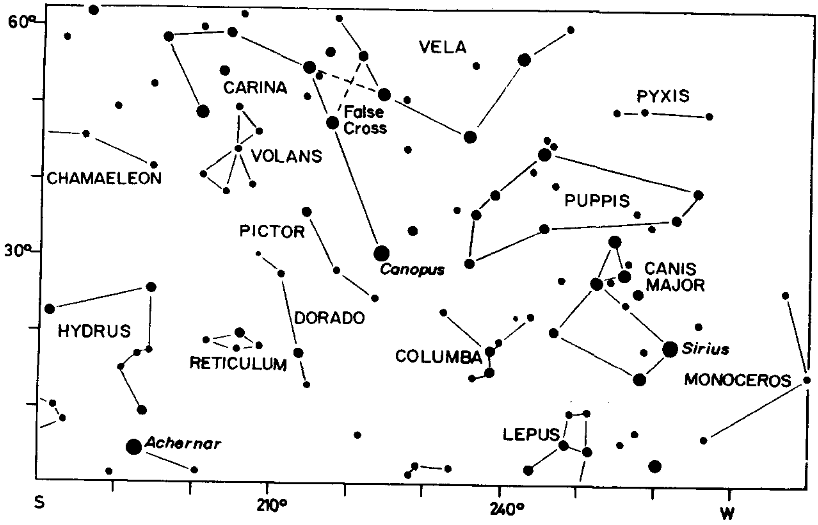




February 6 at 3^h	February 21 at 2^h
March 6 at 1^h	March 21 at midnight
April 6 at 23^h	April 21 at 22^h
May 6 at 21^h	May 21 at 20^h
June 6 at 19^h	June 21 at 18^h

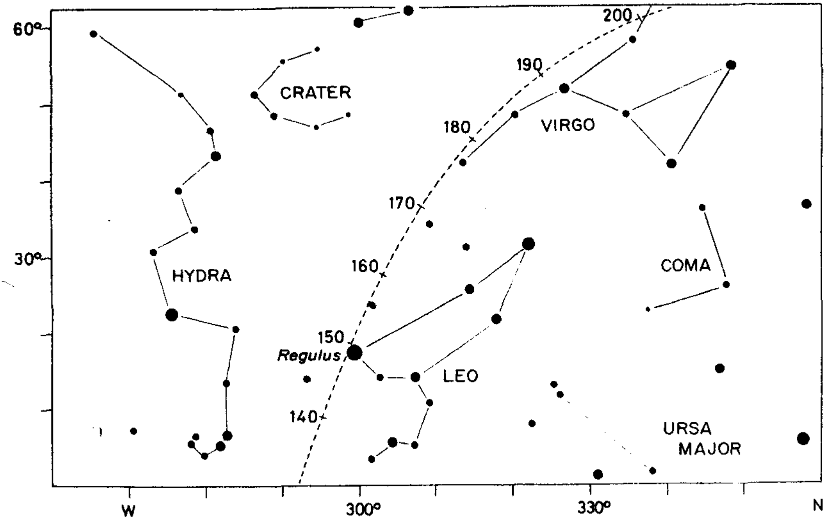
4R

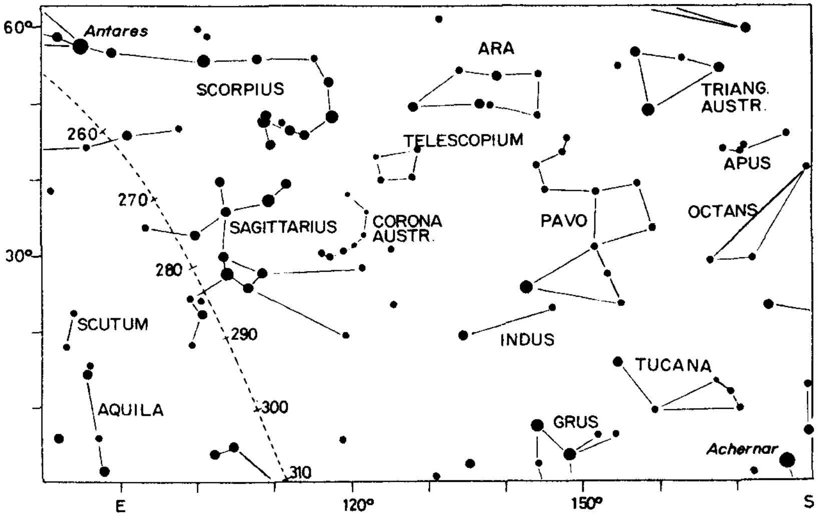




5L

March 6 at 3^h	March 21 at 2^h
April 6 at 1^h	April 21 at midnight
May 6 at 23^h	May 21 at 22^h
June 6 at 21^h	June 21 at 20^h
July 6 at 19^h	July 21 at 18^h

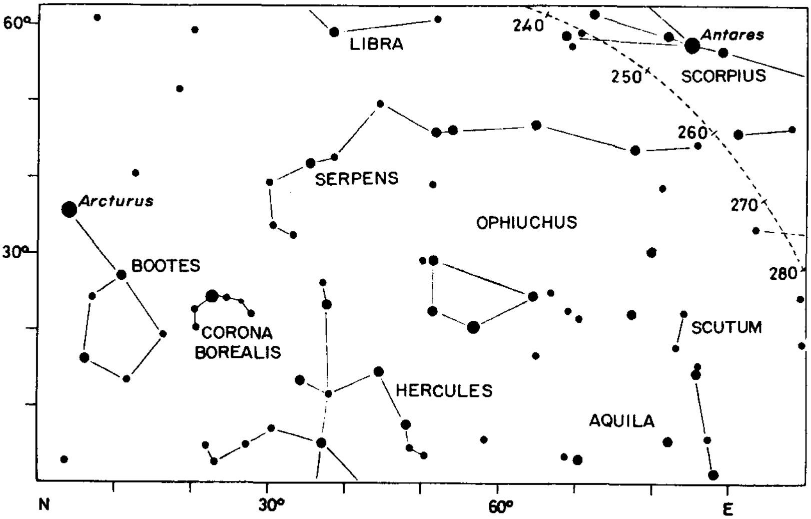


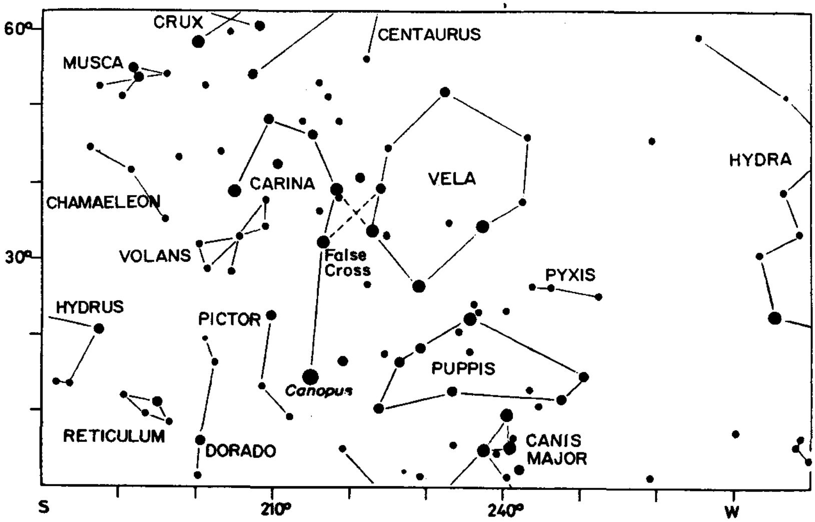


March 6 at 3^h
April 6 at 1^h
May 6 at 23^h
June 6 at 21^h
July 6 at 19^h

March 21 at 2^h
April 21 at midnight
May 21 at 22^h
June 21 at 20^h
July 21 at 18^h

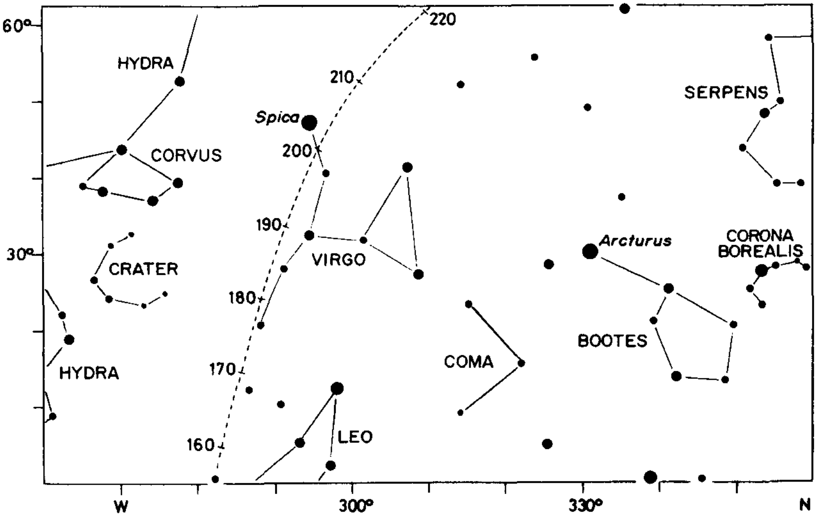
5R

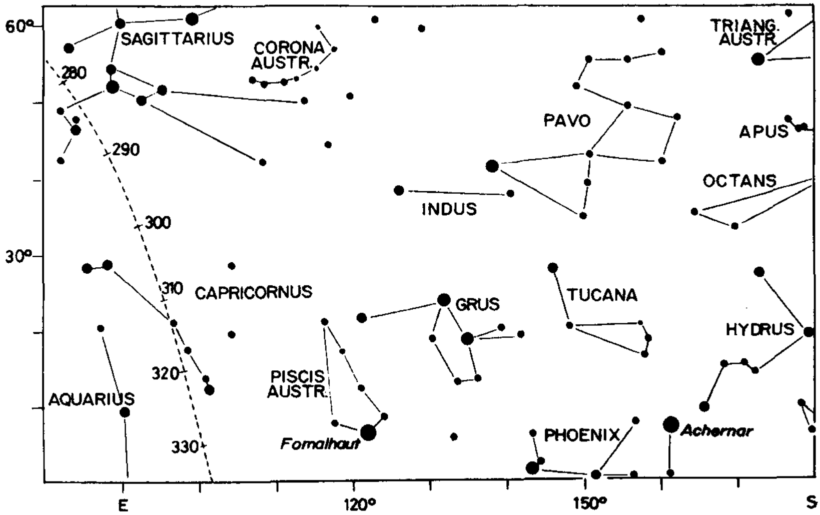




6L

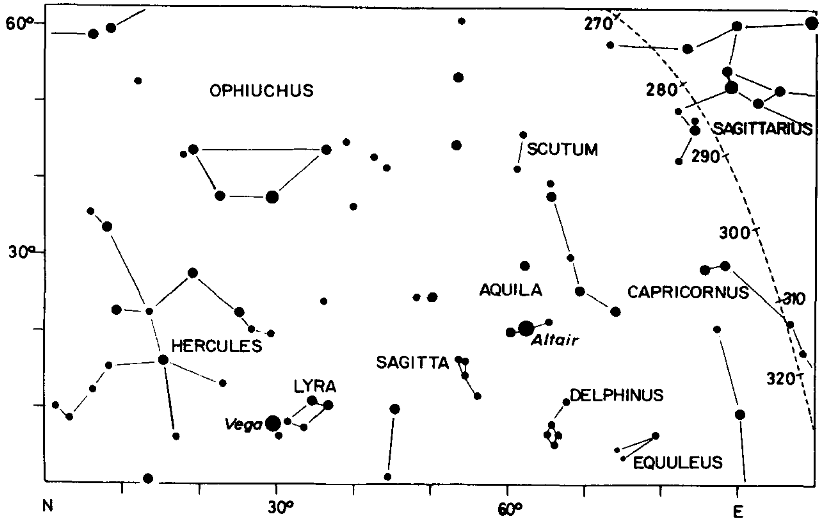
March 6 at 5h	March 21 at 4h
April 6 at 3h	April 21 at 2h
May 6 at 1h	May 21 at midnight
June 6 at 23h	June 21 at 22h
July 6 at 21h	July 21 at 20h

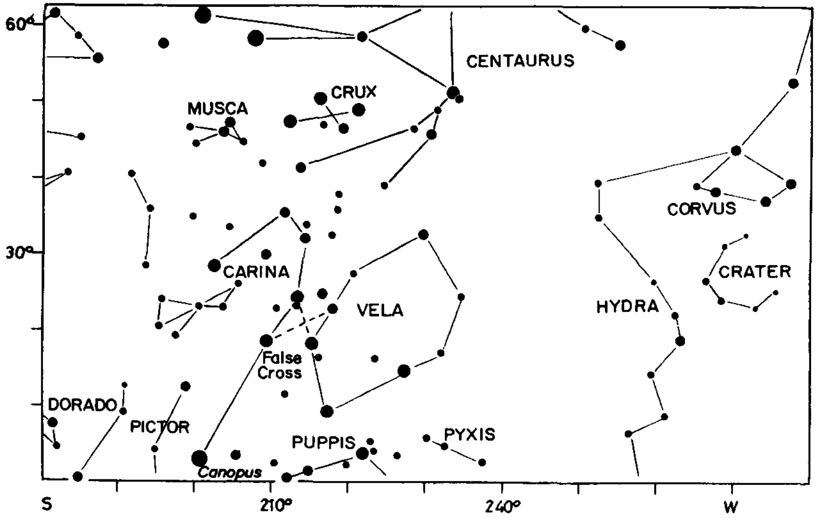




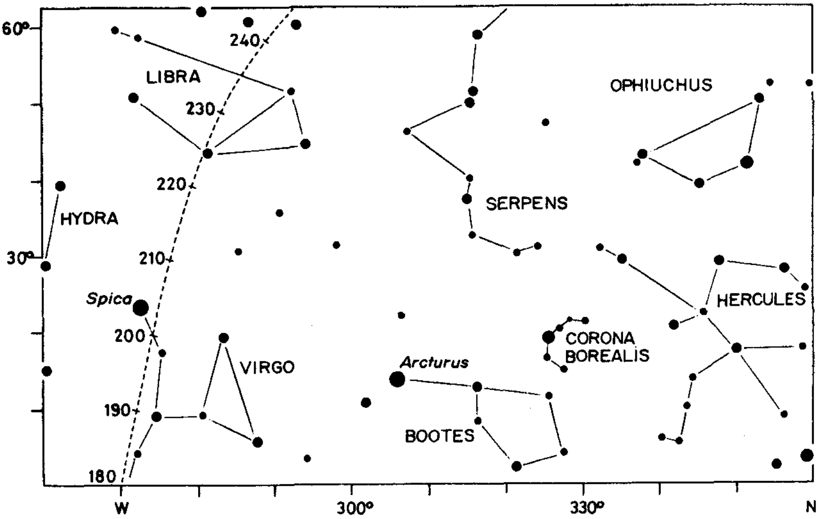
March 6 at 5^h	March 21 at 4^h
April 6 at 3^h	April 21 at 2^h
May 6 at 1^h	May 21 at midnight
June 6 at 23^h	June 21 at 22^h
July 6 at 21^h	July 21 at 20^h

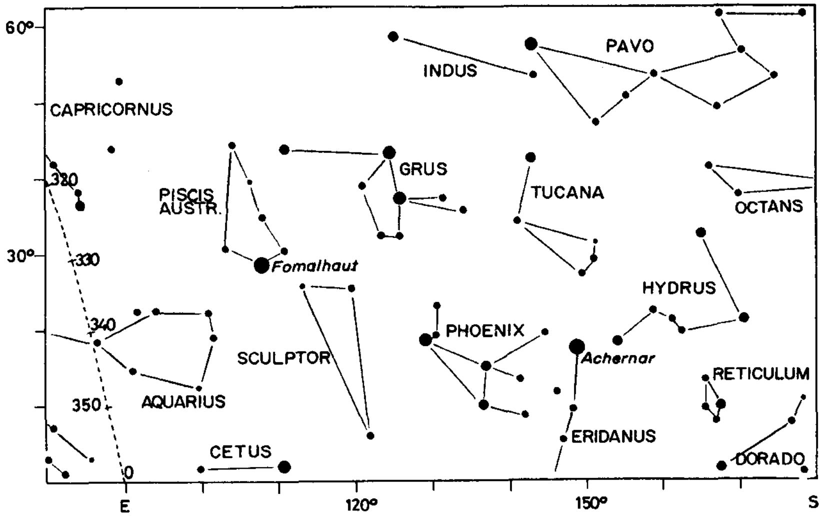
6R





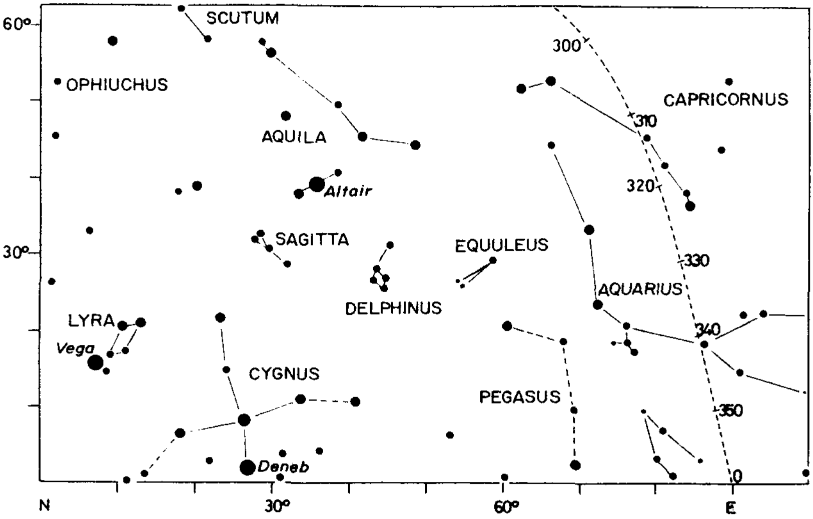
7L	April 6 at 5^h	April 21 at 4^h
	May 6 at 3^h	May 21 at 2^h
	June 6 at 1^h	June 21 at midnight
	July 6 at 23^h	July 21 at 22^h
	August 6 at 21^h	August 21 at 20^h

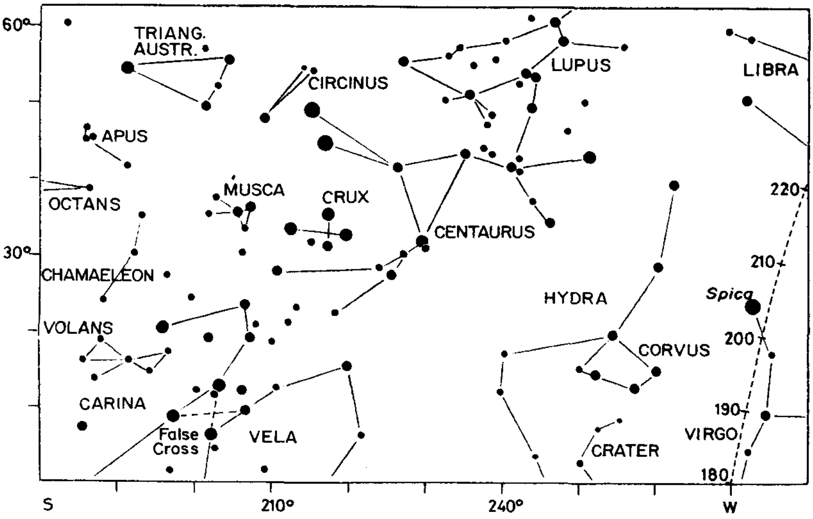




April 6 at 5^h	April 21 at 4^h
May 6 at 3^h	May 21 at 2^h
June 6 at 1^h	June 21 at midnight
July 6 at 23^h	July 21 at 22^h
August 6 at 21^h	August 21 at 20^h

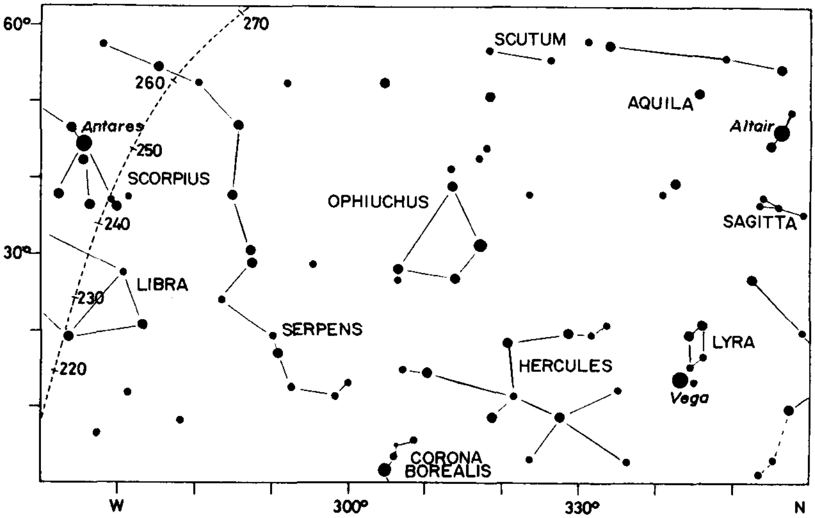
7R

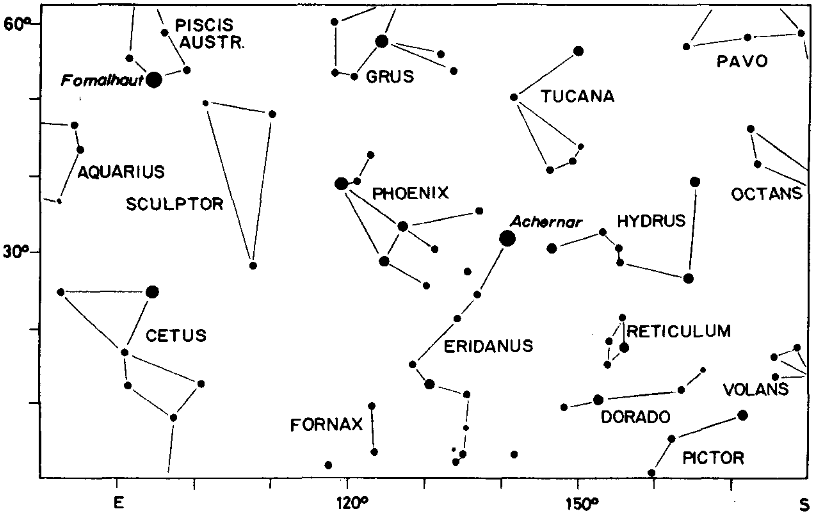




8L

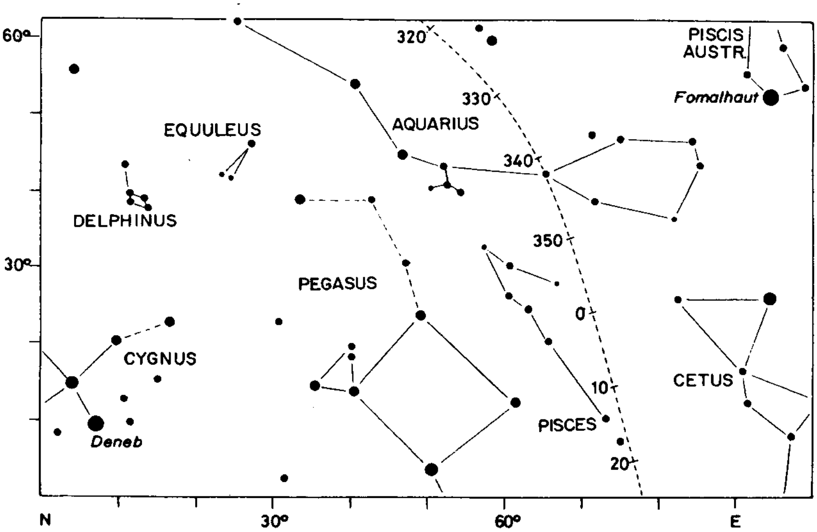
May 6 at 5h	May 21 at 4h
June 6 at 3h	June 21 at 2h
July 6 at 1h	July 21 at midnight
August 6 at 23h	August 21 at 22h
September 6 at 21h	September 21 at 20h

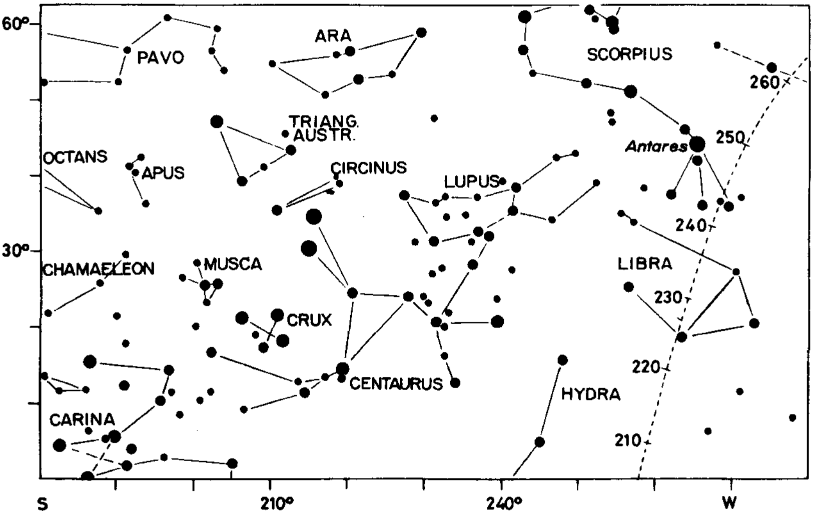




May 6 at 5^h	May 21 at 4^h
June 6 at 3^h	June 21 at 2^h
July 6 at 1^h	July 21 at midnight
August 6 at 23^h	August 21 at 22^h
September 6 at 21^h	September 21 at 20^h

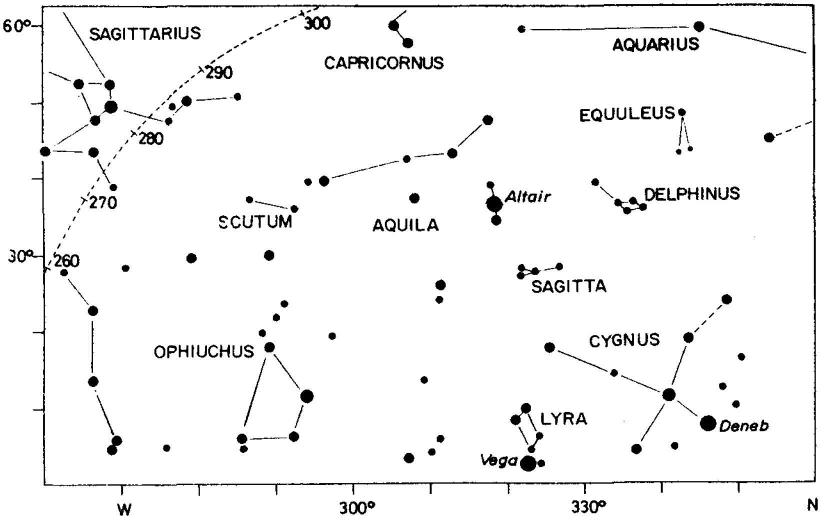
8R

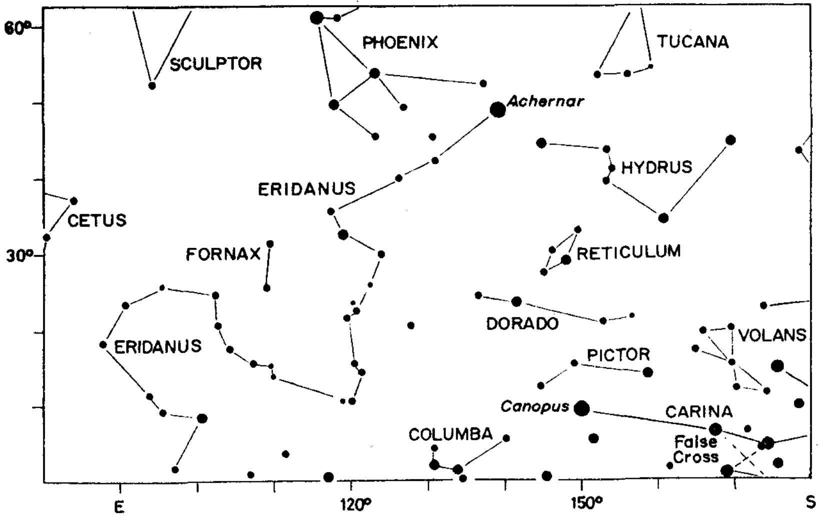




9L

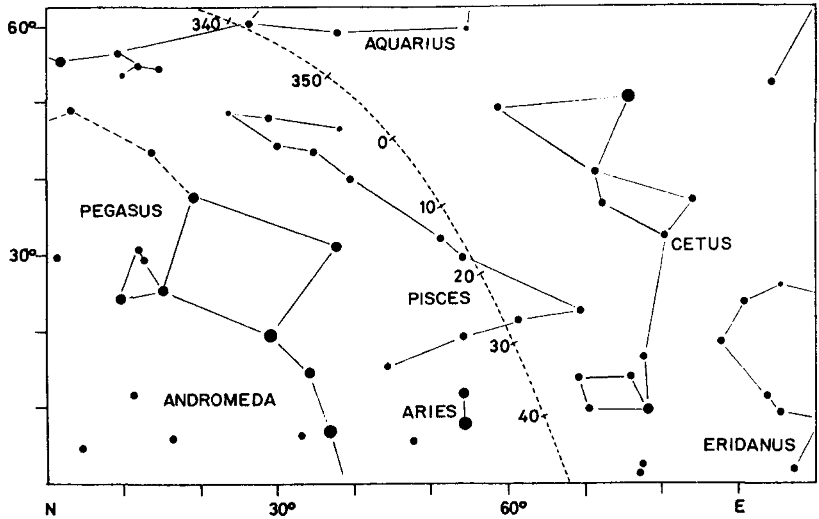
June 6 at 5^h	June 21 at 4^h
July 6 at 3^h	July 21 at 2h
August 6 at 1^h	August 21 at midnight
September 6 at 23^h	September 21 at 22^h
October 6 at 21^h	October 21 at 20^h

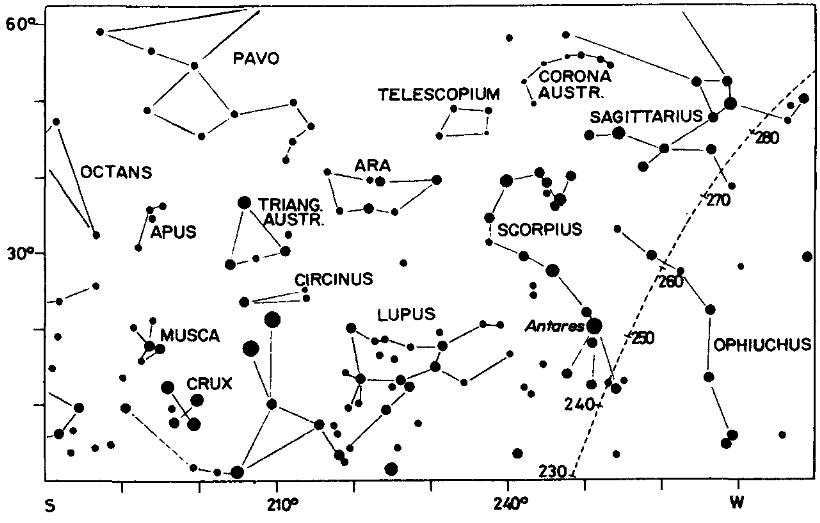




June 6 at 5^h June 21 at 4^h
July 6 at 3^h July 21 at 2h
August 6 at 1^h August 21 at midnight
September 6 at 23^h September 21 at 22^h
October 6 at 21^h October 21 at 20^h

9R

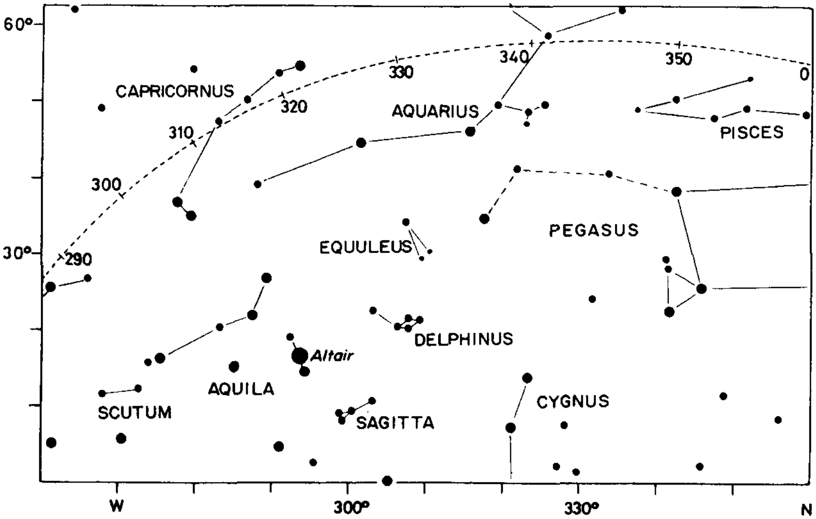


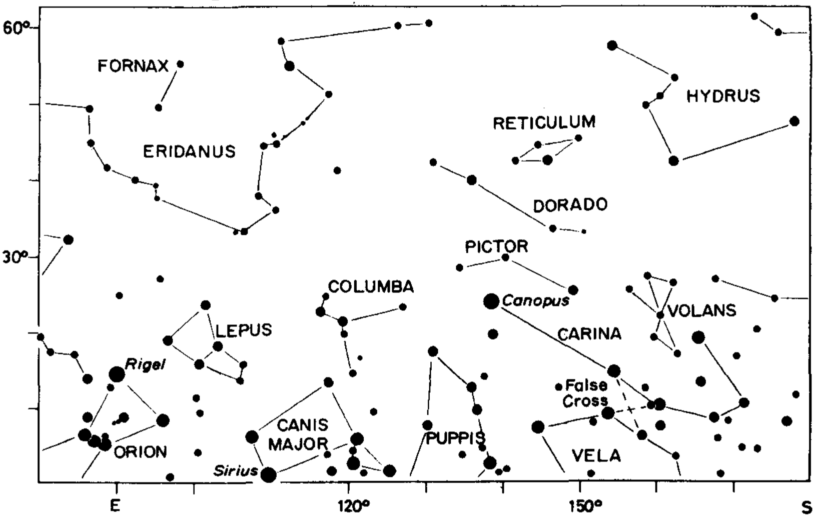


10L

July 6 at 5^h
August 6 at 3^h
September 6 at 1^h
October 6 at 23^h
November 6 at 21^h

July 21 at 4^h
August 21 at 2^h
September 21 at midnight
October 21 at 22^h
November 21 at 20^h

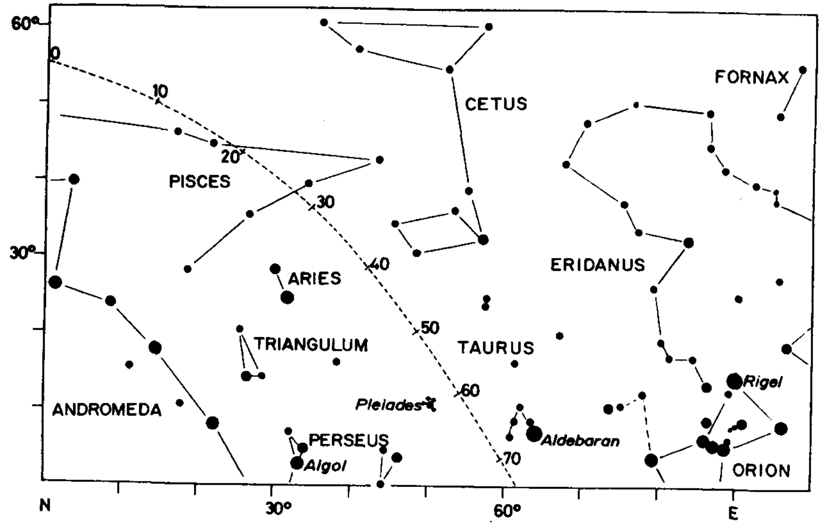


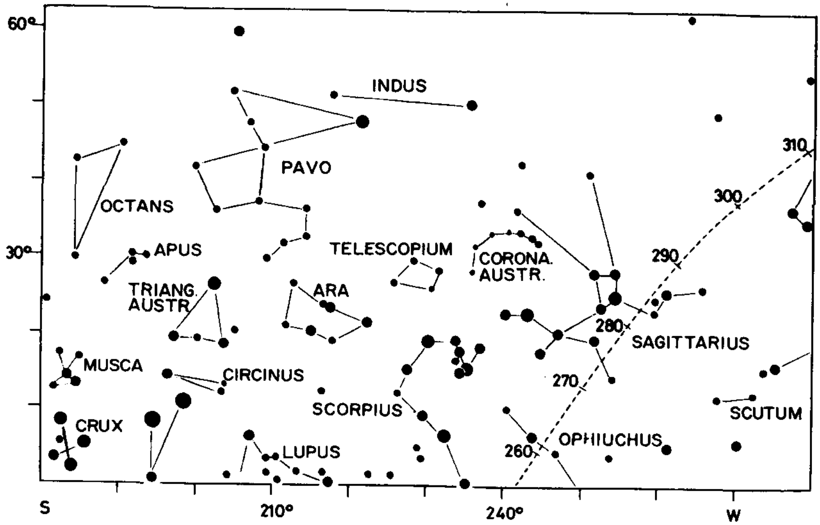


July 6 at 5^h
August 6 at 3^h
September 6 at 1^h
October 6 at 23^h
November 6 at 21^h

July 21 at 4^h
August 21 at 2^h
September 21 at midnight
October 21 at 22^h
November 21 at 20^h

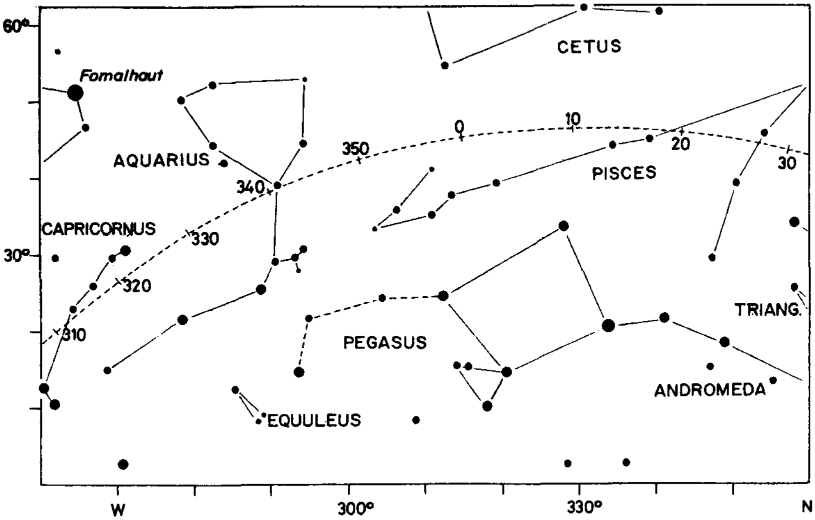
10R

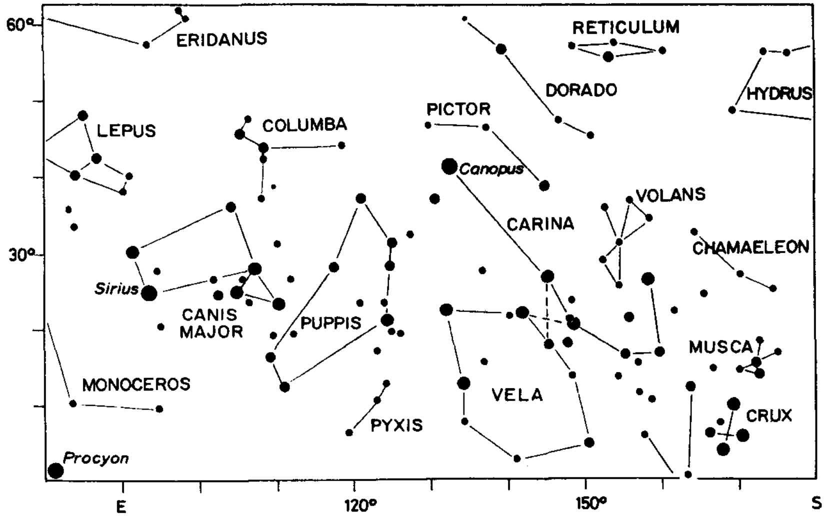




11L

August 6 at 5^h	August 21 at 4^h
September 6 at 3^h	September 21 at 2^h
October 6 at 1^h	October 21 at midnight
November 6 at 23^h	November 21 at 22^h
December 6 at 21^h	December 21 at 20^h

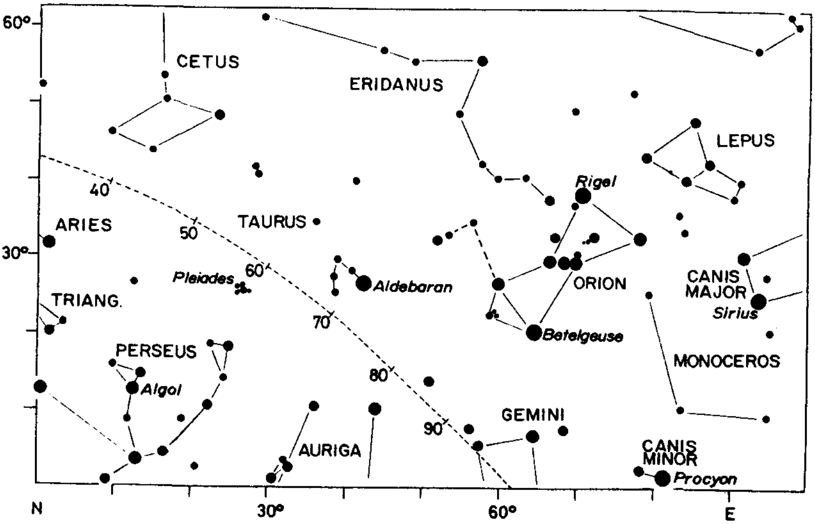


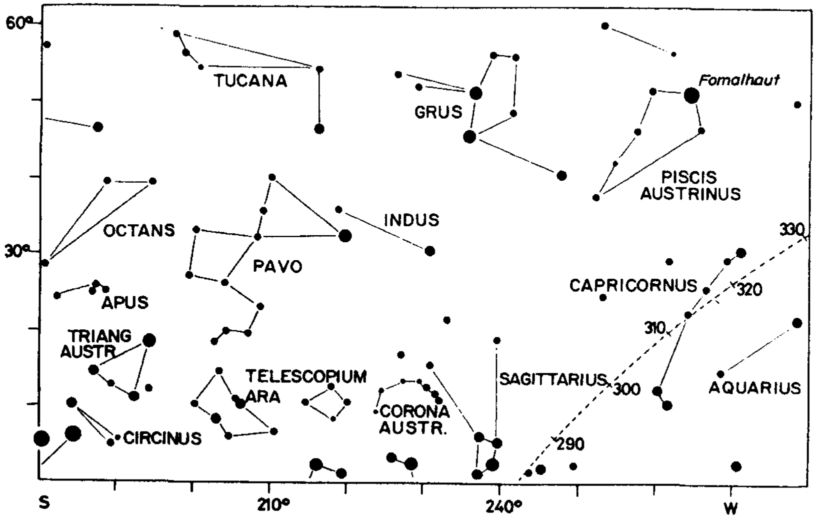


August 6 at 5^h
September 6 at 3^h
October 6 at 1^h
November 6 at 23^h
December 6 at 21^h

August 21 at 4^h
September 21 at 2^h
October 21 at midnight
November 21 at 22^h
December 21 at 20^h

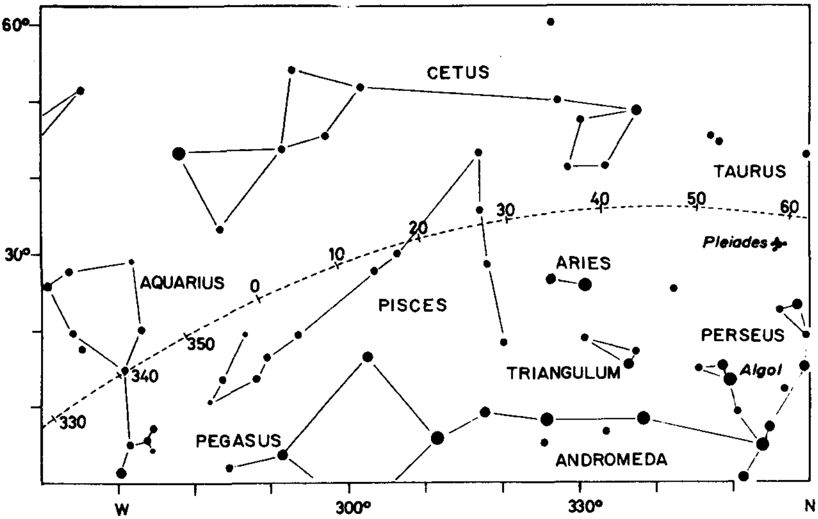
11R

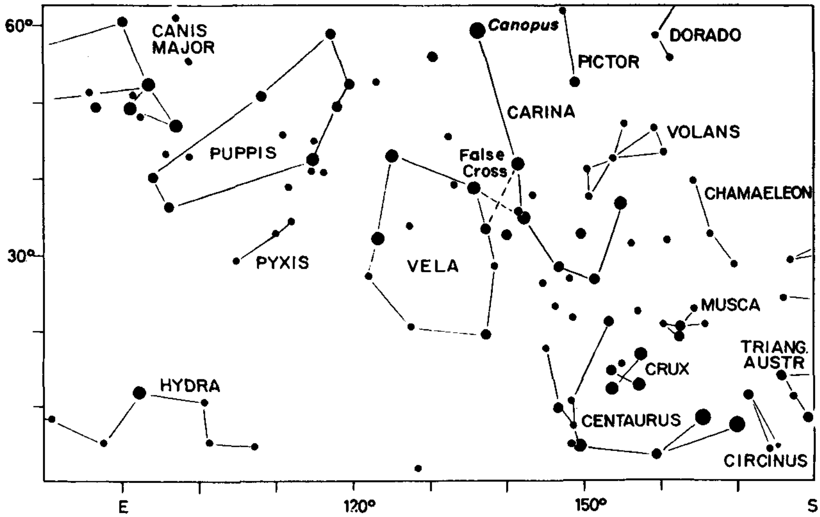




12L

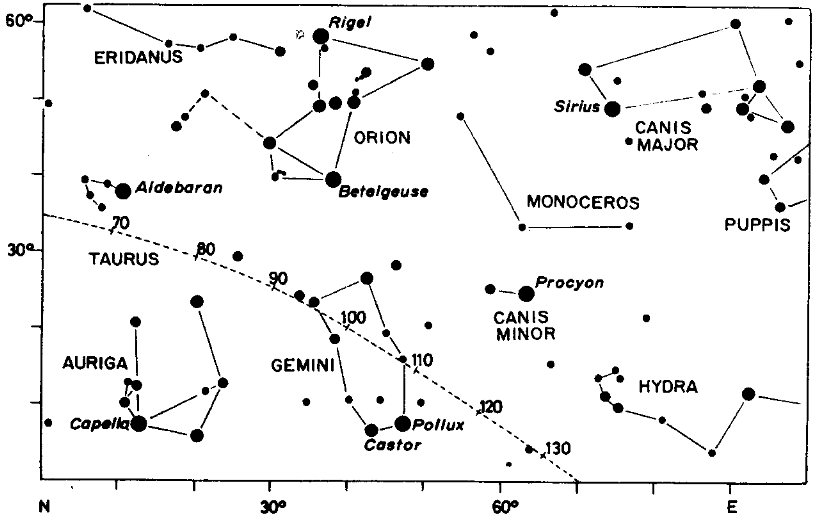
September 6 at 5^{h}	September 21 at 4^{h}
October 6 at 3^{h}	October 21 at 2^{h}
November 6 at 1^{h}	November 21 at midnight
December 6 at 23^{h}	December 21 at 22^{h}
January 6 at 21^{h}	January 21 at 20^{h}

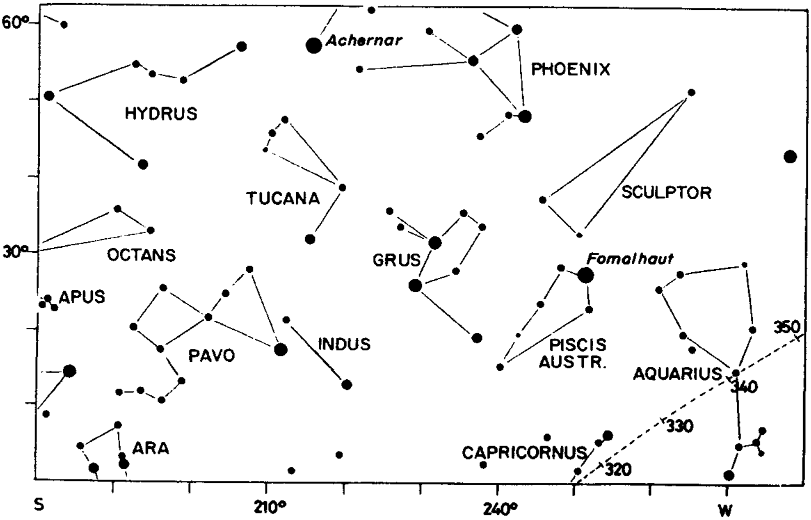


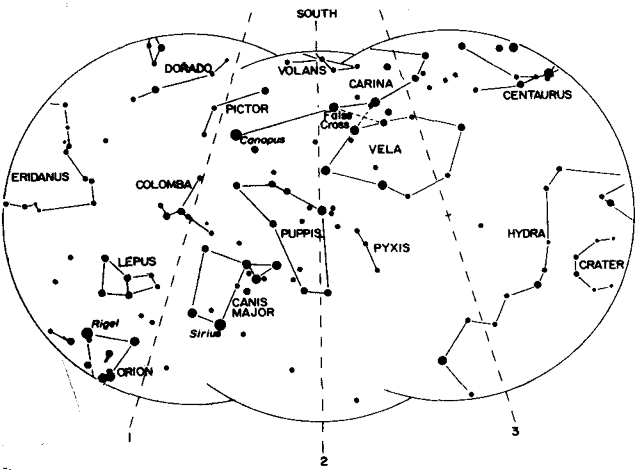


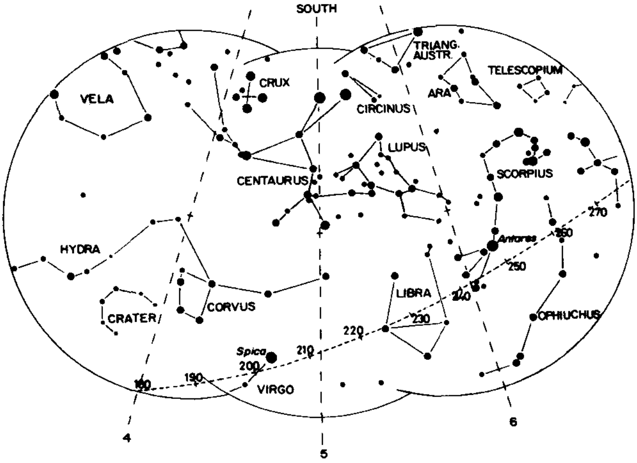
September 6 at 5^h	September 21 at 4^h
October 6 at 3^h	October 21 at 2^h
November 6 at 1^h	November 21 at midnight
December 6 at 23^h	December 21 at 22^h
January 6 at 21^h	January 21 at 20^h

12R

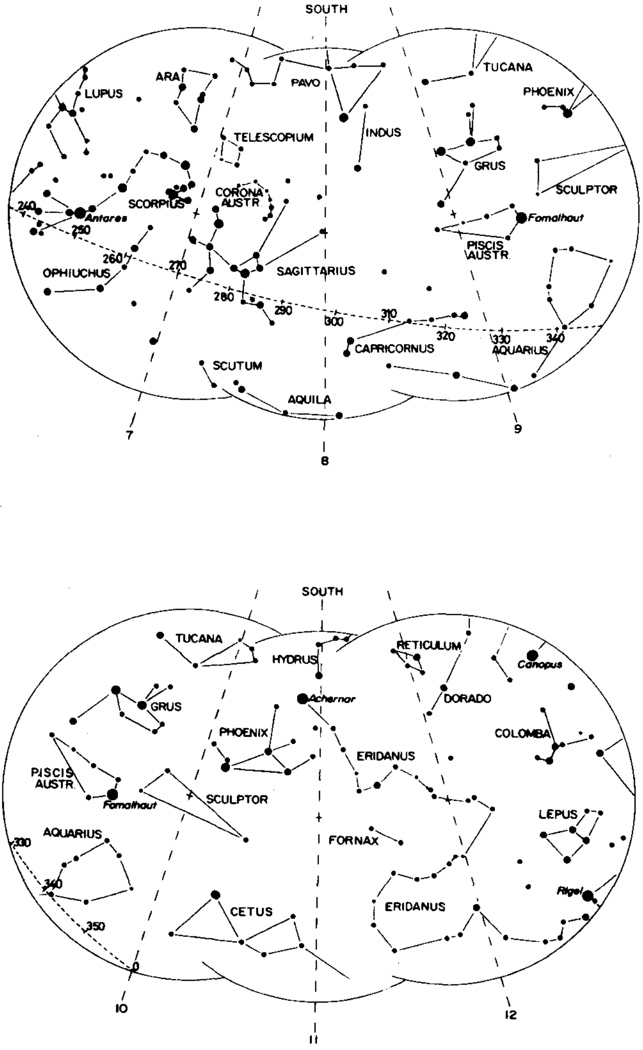








Southern Hemisphere Overhead Stars



Southern Hemisphere Overhead Stars

The Planets and the Ecliptic

The paths of the planets about the Sun all lie close to the plane of the ecliptic, which is marked for us in the sky by the apparent path of the Sun among the stars, and is shown on the star charts by a broken line. The Moon and planets will always be found close to this line, never departing from it by more than about 7 degrees. Thus the planets are most favourably placed for observation when the ecliptic is well displayed, and this means that it should be as high in the sky as possible. This avoids the difficulty of finding a clear horizon, and also overcomes the problem of atmospheric absorption, which greatly reduces the light of the stars. Thus a star at an altitude of 10 degrees suffers a loss of 60 per cent of its light, which corresponds to a whole magnitude; at an altitude of only 4 degrees, the loss may amount to two magnitudes.

The position of the ecliptic in the sky is therefore of great importance, and since it is tilted at about 23½ degrees to the equator, it is only at certain times of the day or year that it is displayed to the best advantage. It will be realized that the Sun (and therefore the ecliptic) is at its highest in the sky at noon in midsummer, and at its lowest at noon in midwinter. Allowing for the daily motion of the sky, these times lead to the fact that the ecliptic is highest at midnight in winter, at sunset in the spring, at noon in summer and at sunrise in the autumn. Hence these are the best times to see the planets. Thus, if Venus is an evening star, in the western sky after sunset, it will be seen to best advantage if this occurs in the spring, when the ecliptic is high in the sky and slopes down steeply to the north-west. This means that the planet is not only higher in the sky, but will remain for a much longer period above the horizon. For similar reasons, a morning star will be seen at its best on autumn mornings before sunrise, when the ecliptic is high in the east. The outer planets, which can come to opposition (i.e. opposite the Sun), are best seen when opposition occurs in the winter months, when the ecliptic is high in the sky at midnight.

The seasons are reversed in the Southern Hemisphere, spring beginning at the September Equinox, when the Sun crosses the Equator on its way south, summer begins at the December Solstice, when the Sun is highest in the southern sky, and so on. Thus, the times when the ecliptic is highest in the sky, and therefore best placed for observing the planets, may be summarised as follows:

	Midnight	*Sunrise*	*Noon*	*Sunset*
Northern lats.	December	September	June	March
Southern lats.	June	March	December	September

In addition to the daily rotation of the celestial sphere from east to west, the planets have a motion of their own among the stars. The apparent movement is generally *direct,* i.e. to the east, in the direction of increasing longitude, but for a certain period (which depends on the distance of the planet) this apparent motion is reversed. With the outer planets this *retrograde* motion occurs about the time of opposition. Owing to the different inclination of the orbits of these planets, the actual effect is to cause the apparent path to form a loop, or sometimes an S-shaped curve. The same effect is present in the motion of the inferior planets, Mercury and Venus, but it is not so obvious, since it always occurs at the time of inferior conjunction.

The inferior planets, Mercury and Venus, move in smaller orbits than that of the Earth, and so are always seen near the Sun. They are most obvious at the times of greatest angular distance from the Sun (greatest elongation), which may reach 28 degrees for Mercury, or 47 degrees for Venus. They are then seen as evening stars in the western sky after sunset (at eastern elongations) or as morning stars in the eastern sky before sunrise (at western elongations). The succession of phenomena, conjunctions and elongations, always follows the same order, but the intervals between them are not equal. Thus, if either planet is moving round the far side of its orbit its motion will be to the east, in the same direction in which the Sun appears to be moving. It therefore takes much longer for the planet to overtake the Sun—that is, to come to superior conjunction—than it does when moving round to inferior conjunction, between Sun and Earth. The intervals given in the following table are average values; they remain fairly constant in the case of Venus, which travels in an almost circular orbit. In the case of Mercury, however, conditions vary widely because of the great eccentricity and inclination of the planet's orbit.

		Mercury	*Venus*
Inferior conj.	to Elongation West	22 days	72 days
Elongation West	to Superior conj.	36 days	220 days
Superior conj.	to Elongation East	36 days	220 days
Elongation East	to Inferior conj.	22 days	72 days

The greatest brilliancy of Venus always occurs about 36 days before or after inferior conjunction. This will be about a month *after* greatest eastern elongation (as an evening star), or a month *before* greatest western elongation (as a morning star). No such rule can be given for Mercury, because its distance from the Earth and the Sun can vary over a wide range.

Mercury is not likely to be seen unless a clear horizon is available. It is seldom seen as much as 10 degrees above the horizon in the twilight sky in northern latitudes, but this figure is often exceeded in the Southern Hemisphere. This favourable condition arises because the maximum elongation of 28 degrees can occur only when the planet is at aphelion (farthest from the Sun), and this point lies well south of the Equator. Northern observers must be content with smaller elongations, which may be as little as 18 degrees at perihelion. In general, it may be said that the most favourable times for seeing Mercury as an evening star will be in spring, some days before greatest eastern elongation; in autumn, it may be seen as a morning star some days after greatest western elongation.

Venus is the brightest of the planets, and may be seen on occasions in broad daylight. Like Mercury, it is alternately a morning and an evening star, and will be highest in the sky when it is a morning star in autumn, or an evening star in spring. The phenomena of Venus given in the table above can occur only in the months of January, April, June, August and November, and it will be realized that they do not all lead to favourable apparitions of the planet. In fact, Venus is to be seen at its best as an evening star in northern latitudes when eastern elongation occurs in June. The planet is then well north of the Sun in the preceding spring months, and is a brilliant object in the evening sky over a long period. In the Southern Hemisphere a November elongation is best. For similar reasons, Venus gives a prolonged display as a morning star in the months following western elongation in November (in northern latitudes) or in June (in the Southern Hemisphere).

The superior planets, which travel in orbits larger than that of the Earth, differ from Mercury and Venus in that they can be seen opposite the Sun in the sky. The superior planets are morning stars after conjunction with the Sun, rising earlier each day until they come to opposition. They will then be nearest to the Earth (and therefore at their brightest), and will be on the meridian at midnight, due south in northern latitudes, but due north in the Southern Hemisphere. After opposition they are evening stars, setting earlier each evening until they set in the west with the Sun at the next conjunction. The change in brightness about the time of opposition is most noticeable in the case of Mars, whose distance from the Earth can vary considerably and rapidly. The other superior planets are at such great distances that there is very little change in brightness from one opposition to another. The effect of altitude is, however, of some importance, for at a December opposition in northern latitudes the planet will be among the stars of Taurus or Gemini, and can then be at an altitude of more than 60 degrees in southern England. At a summer opposition, when the planet is in Sagittarius, it may only rise to about 15 degrees above the southern horizon, and so makes a less impressive appearance. In the Southern Hemisphere, the reverse conditions apply; a June opposition being the best, with the planet in Sagittarius at an altitude which can reach 78 degrees above the northern horizon.

Mars, whose orbit is appreciably eccentric, comes nearest to the Earth at an opposition at the end of August. It may then be brighter even than Jupiter, but rather low in the sky in Aquarius for northern observers, though very well placed for those in southern latitudes. These favourable oppositions occur every fifteen or seventeen years (1924, 1941, 1956, 1971) but in the Northern Hemisphere the planet is probably better seen at an opposition in the autumn or winter months, when it is higher in the sky. Oppositions of Mars occur at an average interval of 780 days, and during this time the planet makes a complete circuit of the sky.

Jupiter is always a bright planet, and comes to opposition a month later each year, having moved, roughly speaking, from one Zodiacal constellation to the next.

Saturn moves much more slowly than Jupiter, and may remain in the same constellation for several years. The brightness of Saturn depends on the aspect of its rings, as well as on the distance from Earth and Sun. The rings are now closing, and are inclined towards the Earth and Sun at quite a small angle. They will be seen edge-on in1979 and again in 1980.

Uranus, Neptune, and *Pluto* are hardly likely to attract the attention of observers without adequate instruments, but some notes on their present positions in the sky will be found in the April, May and June Notes.

Phases of the Moon 1979

New Moon				*First Quarter*				*Full Moon*				*Last Quarter*			
	d	h	m		d	h	m		d	h	m		d	h	m
				Jan.	5	11	15	Jan.	13	07	09	Jan.	21	11	23
Jan.	28	06	20	Feb.	4	00	36	Feb.	12	02	39	Feb.	20	01	17
Feb.	26	16	45	Mar.	5	16	23	Mar.	13	21	14	Mar.	21	11	22
Mar.	28	02	59	Apr.	4	09	57	Apr.	12	13	15	Apr.	19	18	30
Apr.	26	13	15	May	4	04	25	May	12	02	01	May	18	23	57
May	26	00	00	June	2	22	37	June	10	11	55	June	17	05	01
June	24	11	58	July	2	15	24	July	9	19	59	July	16	10	59
July	24	01	41	Aug.	1	05	57	Aug.	8	03	21	Aug.	14	19	02
Aug.	22	17	10	Aug.	30	18	09	Sept.	6	10	59	Sept.	13	06	15
Sept.	21	09	47	Sept.	29	04	20	Oct.	5	19	35	Oct.	12	21	24
Oct.	21	02	23	Oct.	28	13	06	Nov.	4	05	47	Nov.	11	16	24
Nov.	19	18	04	Nov.	26	21	09	Dec.	3	18	08	Dec.	11	13	59
Dec.	19	08	23	Dec.	26	05	11	Jan.	2	09	02	Jan.	10	11	49

All times are G.M.T.

Reproduced, with permission, from data supplied by the Science Research Council.

The Planets in 1979

DATE		*Venus*	*Mars*	*Jupiter*	*Saturn*	*Uranus*	*Neptune*
January	6	240°	289°	127°	165°	230°	259°
	21	254	300	125	164	231	260
February	6	271	313	123	163	231	260
	21	287	325	121	162	231	260
March	6	302	335	120	161	231	261
	21	320	347	119	160	231	261
April	6	340	0	119	159	230	261
	21	358	11	120	158	230	260
May	6	16	23	122	158	229	260
	21	34	34	124	158	229	260
June	6	53	46	126	158	228	259
	21	71	56	129	159	228	259
July	6	90	67	132	160	227	259
	21	108	77	135	162	227	258
August	6	128	88	139	164	227	258
	21	147	98	142	165	227	258
September	6	167	109	145	167	228	258
	21	185	118	149	169	228	258
October	6	204	127	152	171	229	258
	21	222	135	154	173	230	259
November	6	242	144	157	175	231	259
	21	260	151	159	176	232	260
December	6	279	158	160	177	233	260
	21	298	163	161	178	234	261
Opposition:		——	——	Jan. 24	Mar. 1	May 10	June 10
Conjunction:		Aug. 25	Jan. 20	Aug. 13	Sep. 10	Nov. 14	Dec. 12

Mercury moves so quickly among the stars that it is not possible to indicate its position on the star charts at a convenient interval. The monthly notes must be consulted for the best times at which the planet may be seen.

The positions of the other planets are given in the table on the previous page. This gives the apparent longitudes on dates which correspond to those of the star charts, and the position of the planet may at once be found near the ecliptic at the given longitude.

Examples:

(1) *Where may an observer look for Mars in the first week of October?*
The table opposite gives the longitude of Mars at this time as 127 degrees. In northern latitudes the lower chart 11R shows that Mars is in Cancer, rising to the north of east at about 1^h. Southern observers will need to use chart 12R, showing that the planet does not rise in those latitudes until about 3^h.

(2) *What is the bright planet seen south of the figure of Leo at* 22^h *on 20 March?*
Northern observers will find chart 3L applies to this date and time, while those in southern latitudes will use southern chart 3R. In either case the longitude is seen to be about 160 degrees, and the table opposite shows the planet to be Saturn.

(3) *Identify the two bright planets seen in the east on either side of Regulus at about* 3^h *on 5 November.*
Northern chart 1L and southern chart 1R are appropriate in this case, and the longitudes on either side of Regulus are seen to be about 140 and 160 degrees. The table opposite shows that the planets must be Mars (144 degrees) to the west of Regulus, and Jupiter (157 degrees) to the east. The monthly notes for November show the situation in greater detail.

Events of 1979

ECLIPSES

In 1979 there will be four eclipses, two of the Sun and two of the Moon.

26 February—a total eclipse of the Sun, visible in N. America and as a partial eclipse in western Europe.

13 March—a partial eclipse of the Moon, visible in Australasia, Africa, Europe and America.

22 August—an annular eclipse of the Sun, visible in Antarctica.

6 September—a total eclipse of the Moon, visible in America, Australasia and Asia.

THE PLANETS

Mercury may best be seen in northern latitudes as an evening star about the time of greatest eastern elongation on 8 March, and as a morning star at western elongation on 19 August. In the Southern Hemisphere the best dates are 29 October (evening star) and 21 April (morning star).

Venus will be a morning star for the first half of the year, and will be at greatest elongation on 18 January. Superior conjunction occurs on 25 August.

Mars is in conjunction on 20 January, and there is no opposition during the year.

Jupiter is at opposition on 24 January in Cancer. After conjunction on 13 August it will be a morning star.

Saturn is at opposition on 1 March in Leo. Conjunction on 10 September.

Uranus is at opposition on 10 May in Libra.

Neptune is at opposition on 10 June in Ophiuchus.

Pluto is at opposition on 8 April in Virgo.

MONTHLY NOTES, 1979

January

Full Moon: 13 January *New Moon:* 28 January

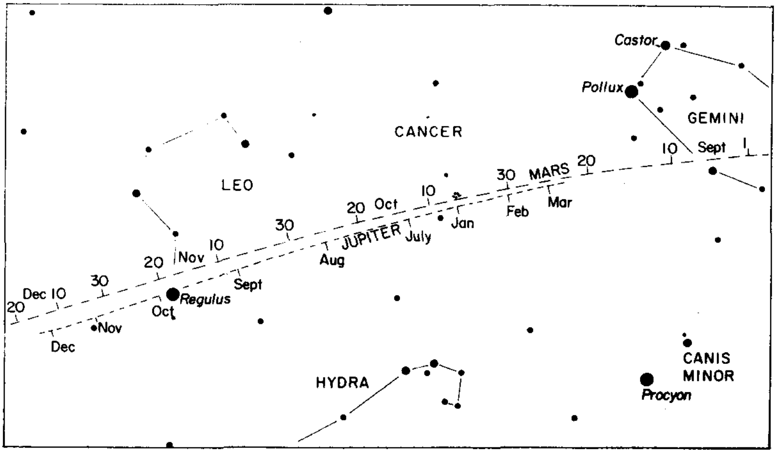
Earth is at perihelion (nearest to the Sun) on 4 January at a distance of 91.4 million miles (147.1 million km).

Mercury is a morning star, and it should be possible to find it low in the south-east at dawn in the first week of January. The planet is quite bright but is well south of the Equator and better placed for observation in the Southern Hemisphere.

Venus is also a morning star and will reach greatest western elongation (47 degrees) on 18 January. A telescope at this time will show the planet to be half-illuminated, like the Moon at Last Quarter. Venus rises to the south of east in a dark sky about three hours before the Sun. It is moving south and will be better placed for observers in the Southern Hemisphere. This is not a very favourable apparition of Venus, and it is now brighter (magnitude –4.3 to –4.1) than it will be for the remainder of the year.

Mars is in conjunction with the Sun on 20 January, and there is no opposition this year. Mars will be very slow to make its appearance as a morning star, and being far south of the Equator it is not likely to be seen, even in the Southern Hemisphere, before April.

Jupiter is at opposition on 24 January, when it reaches magnitude –2.2. Its distance from the Earth is then 399 million miles (642 million km), and it will be found in Cancer, moving retrograde close to the star Delta Cancri and the star cluster M44, which is generally known as Præsepe, the Beehive. The diagram below shows the path of Jupiter during the year, and includes the path of Mars from September onwards.



Saturn rises in the east in the late evening and will be found to the south of the figure of Leo. The planet is moving retrograde (see April notes for diagram), and is growing brighter as it approaches opposition (magnitude +1.0 to +0.8). The rings of Saturn are now tilted at a narrow angle, and will gradually close during the year. The largest satellite, Titan, has a period of 16 days, and will be found at eastern elongation on 7 and 23 January, and at western elongation on 14 and 30 January.

Schröter's Effect. The phases of Venus were first detected by Galileo in 1610, with his primitive telescope, and provided him with one of the main observational proofs that the Earth and planets move round the Sun. (According to the old Ptolemaic theory, with the Earth in the centre, Venus could never have shown a full cycle of phases.) There have been reliable reports that some exceptionally keen-sighted persons can see the phase with the naked eye when Venus is in the crescent stage, and certainly they are easy enough to follow with good binoculars.

Because the orbit of Venus is now so well known, and because the planet shines only by reflected sunlight, it should be easy to predict the time of dichotomy, or exact half-phase. Yet, strangely enough, theory and observation always disagree. When Venus is an evening object and is waning, dichotomy is always early. When Venus is a morning star and is therefore waxing, as happens in this month, dichotomy is always late. The discrepancy may amount to several days. The phenomenon was first noted by Johann Hieronymus Schröter, a famous German lunar and planetary observer of the late eighteenth and early nineteenth centuries. The present Editor of the *Yearbook* referred to this in a lecture given many years ago and called it 'Schröter's Effect', a term which has now found its way into official astronomical literature.

The cause lies, of course, in the thick and extensive atmosphere of Venus. Observers who are studying the planet during this month will have an opportunity to note the moment of dichotomy and see how late it is – though the terminator generally appears straight, or nearly so, for several consecutive days. Neither is the terminator always quite regular; it shows occasional indentations and projections. These are not due to mountains, as was once believed, but are purely phenomena of the upper clouds.

Pluto. On 21 January the distance between Pluto and the Sun is equal to that of Neptune, so that between now and 1999 it will be Neptune, not Pluto, which merits the title of 'the outermost planet'. Further details are given in the notes for April.

Brilliant Zenith Stars. From latitudes such as those of England and the northern United States, the brilliant yellow star Capella is almost overhead during evenings in January. This makes it very easy to recognize. It is the leader of the constellation of Auriga, the Charioteer; close beside it lies the little triangle of stars known as the Hædi or 'Kids', two members of which (Epsilon and Zeta Aurigæ) are giant eclipsing binaries.

The secondary component of Epsilon cannot be seen visually, though it may be detected in the infra-red. It may be either a very young star still condensing, in which case its diameter must exceed 1,700 million miles (big enough to hold the orbit of Uranus round the Sun!) or else a Black Hole. Eclipses of the yellow supergiant primary occur every 27 years; none is due in 1979.

From southern countries such as Australia and South Africa, the even more brilliant Canopus lies near the zenith or overhead point. Canopus looks inferior only to Sirius; actually it is far more luminous, and is very remote. The spectrum is of type F, though most people will describe Canopus as a white star rather than a yellow one. It is the leader of Carina, the keel of the old ship Argo; Argo was so large and cumbersome a constellation that by decree of the International Astronomical Union it was chopped up! Carina also contains the extraordinary variable Eta Carinæ, which is described in Dr. David Allen's article in the present *Yearbook*.

February

Full Moon: 12 February *New Moon:* 26 February

Mercury is at superior conjunction on 9 February and will not be visible until the end of the month, when it begins to appear as an evening star, well placed for northern observers.

Venus is still visible at the dawn sky in the south-east but is best seen in the Southern Hemisphere, where it rises in a dark sky about three hours before sunrise.Venus is now moving round to the far side of its orbit, and as its distance increases the brightness diminishes (magnitude -3.9 to -3.7).

Mars is a morning star, but is only a few degrees from the Sun, and is not yet visible.

Jupiter continues to move retrograde in Cancer, and will be visible for most of the night. In northern latitudes it sets about an hour before sunrise at the end of February, but two hours earlier in the Southern Hemisphere. The planet remains well north of the Equator throughout the year (magnitude -2.2 to -2.1).

Saturn is now appreciably brighter (magnitude +0.7 to +0.5) and rises shortly after sunset. It is moving retrograde in Leo, and should be found quite easily since it is much brighter than any of the stars in that constellation. Titan will be seen at eastern elongation on 7 and 23 February, and at western elongation on the 15th.

A total eclipse of the Sun on 26 February will be visible at

Winnipeg and other stations in the extreme north-west of the United States and in central and eastern Canada. Visible as a partial eclipse throughout North America. For details see page 124.

The Saros. The conditions that apply to any particular eclipse will repeat themselves almost exactly after a period of 6585.32 days (18 years 11 days). This period is known as the Saros, and was familiar to the ancient Assyrian astronomers. Conditions change so slowly that there is always a long series of eclipses, beginning with a small partial eclipse at one pole of the Earth, each successive eclipse moving south (or north) until the series finally ends with a small partial eclipse at the other pole. The eclipse of 26 February occurs near the end of a series which began in the year 933 at the South Pole. There will be three more total eclipses (the last in the year 2033) in this series, which will end with a number of decreasing partial eclipses. This is a typical eclipse series, lasting about 1,300 years, and containing about 70 solar eclipses. A similar, but shorter series is also found among lunar eclipses.

Total eclipses of the Sun. There can be little doubt that a total eclipse is the grandest sight in all Nature. For the few minutes that the Sun is hidden, the chromosphere and the pearly corona may be seen with the naked eye, and sometimes the sky becomes dark enough for planets and brilliant stars to be seen.

This month's eclipse should be well seen over wide areas of Canada. The length of totality is only about 2¼ minutes (in no eclipse can totality last for as long as 8 minutes) but many expeditions will be dispatched, because the present solar cycle has been an unusual one – the level of spot activity during 1977 and early 1978 was lower than might have been expected inasmuch as maximum is due around 1980 – and astronomers will be anxious to study the form of the corona. This is impossible except during totality, or from space-probes, though of course the prominences and the chromosphere can be studied at any time by means of special instruments. The form of the corona at the eclipse of 26 February will therefore be of special interest. (Note the comments by Miss Botley in her article on 'The Maunder Minimum' in this *Yearbook*.)

It is important to remember that when even the slightest portion of the solar photosphere is visible, looking direct at the Sun with binoculars or a telescope is to invite permanent blindness even if a dark filter is used. Neither is it wise to look at the eclipsed Sun, because totality ends with surprising suddenness.

Lost Comets. Holmes' periodical comet is scheduled to return to perihelion this month (see page 128). This comet was 'lost' for many years after 1908, and was regarded as being probably defunct. Such an event would not be unknown. The classic case is that of Biela's Comet, which during its return in 1846 split into two parts; the twins were seen at the next return, that of 1852, but have not been observed since, and there can be no doubt that the comet has disintegrated; it is associated with a meteor shower seen annually in November (though generally the 'Bieliid' meteor shower is now extremely feeble). Brorsen's periodical comet, observed during the nineteenth century, has also ceased to exist, and the same is no doubt true of Westphal's, which had a much longer period.

On the other hand, it is always dangerous to be dogmatic! Holmes' Comet was recovered as a result of some very precise calculations made by Brian Marsden in the United States, though it is now very faint (at its discovery year, in 1892, it was on the fringe of naked-eye visibility). It is not impossible that some other 'lost' comets of short period will be recovered in the future, though it is true that compared with planets a short-period comet has a very limited lifetime. The other periodical comet due to return to perihelion this month (Giacobini-Zinner) was associated with a brilliant shower of meteors seen in 1933.

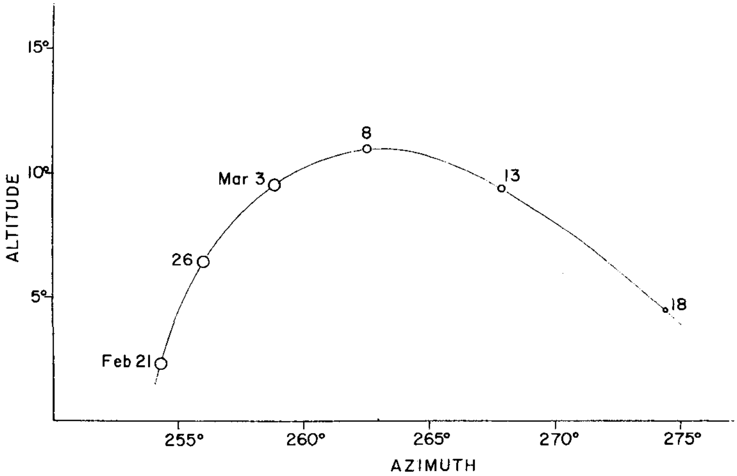
March

Full Moon: 13 March *New Moon:* 28 March

Summer Time in Great Britain and Northern Ireland commences on 18 March.

Equinox: 21 March

Mercury is at greatest eastern elongation on 8 March (18 degrees) and is then an evening star, well placed for observers in the Northern Hemisphere. The diagram shows the changes in altitude and azimuth (true bearing from the north through east, south and west) of Mercury on successive evenings when



the Sun is 6 degrees below the horizon in latitude 52 degrees north (this is about 35 minutes after sunset). The changes in brightness are roughly indicated by the size of the circles, and it will be seen that Mercury is brightest *before* the date of eastern elongation.

Mercury is in inferior conjunction on 24 March.

Venus is still well south of the Equator and southern observers will be able to see this planet in the morning sky for about three hours before sunrise. In northern latitudes Venus rises only about an hour before the Sun. By the end of the month, the planet will be only half as bright as it was at the beginning of the year (magnitude -3.7 to -3.5).

Mars begins to appear as a morning star but it is still south of the Equator and not very bright (magnitude +1.4). By the end of March, it rises more than an hour before the Sun in latitude 35 degrees south, but is hardly likely to be seen in the bright dawn sky. Mars is at perihelion on 18 March but is then on the far side of its orbit. The next opposition of Mars will therefore occur when the planet is at aphelion, the least favourable 'close approach'.

Jupiter is an evening star, visible until dawn in northern latitudes, but setting about an hour after midnight in the Southern Hemisphere. The planet's retrograde motion becomes slower and it reaches a stationary point on 26 March on the borders of Cancer and Gemini. It is then in line with the Twins, Castor and Pollux (see diagram in January notes), but very much brighter then either (magnitude -2.1 to -1.9).

Saturn is at opposition on 1 March and will be found in Leo, south of the well-known figure. The distance of the planet at opposition is 775 million miles (1,247 million km). The rings, which provide much of the brightness of Saturn, are tilted at a narrow angle (now about 6 degrees), and the planet's magnitude is only +0.5. It can be almost a whole magnitude brighter than this when the rings are wide open, as in 1973. Titan is at eastern elongation on 11 and 27 March, and at western elongation on 3 and 19 March.

A partial eclipse of the Moon on 13 March will be visible in the British Isles and South Africa. Details are given on page 124.

Voyager to Jupiter. Early this month the Voyager 1 probe is scheduled to make its rendezvous with Jupiter; it will also survey the satellites Callisto, Ganymede, Io (from close range) and Amalthea. It will then go on towards a rendezvous with Saturn in November 1980. Though Voyager 1 was launched after Voyager 2 (5 September 1977, as against 20 August) it is travelling by a more economical route, and will take less time to reach its targets.

The beauty of Saturn. It is generally said that the planet Saturn is the most beautiful object in the entire sky. When the ring-system is wide open, as during the mid-1970s, this is certainly true, but this year (1979) things are different. The rings are turning edgewise-on to us, and will become difficult to see at all; during the edgewise presentation they will be seen only as a thin line of light, and observers with small telescopes will lose them completely. However, the rings are still on view during the present month, and observers will be wise to look at them before it is too late! Of course, the system will soon reappear, and by the mid-1980s Saturn will have regained its loveliness.

It is hardly necessary to add that the rings do not actually close up and open out! Everything depends upon the angle from which we see them.

This month's lunar eclipse. Lunar eclipses are not nearly so important as those of the Sun, and are caused in a completely different way. At a solar eclipse, the brilliant disk of the Sun is covered up by the Moon; strictly speaking this is not an eclipse at all, but an occultation of the Sun. When the Moon is eclipsed, it passes into the cone of shadow cast by the Earth; the supply of direct sunlight is cut off, and the Moon becomes dim before it emerges from the shadow again. At some total eclipses the Moon may become difficult to see at all. This month's eclipse is not total, but it will be worth watching, and there may well be a chance to see some of the beautiful coloured effects which so often occur. It may be added that there is no possible danger from looking straight at the full moon through a telescope, because the amount of heat we receive is absolutely negligible, and the worst that can happen is that the observer may be dazzled for a few minutes.

It is also worth noting that as seen from any particular point on the Earth's surface, lunar eclipses are more frequent than those of the Sun. This is because a solar eclipse is visible only over a relatively narrow area, whereas a lunar eclipse can be seen from any position at which the Moon is above the horizon at the time. For instance, the next total eclipse of the Sun to be visible from England will not occur until 1999, and even then the track will be confined to part of Cornwall, but there will be several total lunar eclipses before then.

The largest constellation. The constellations are of various sizes and shapes; Sir John Herschel, during the last century, commented that they had apparently been designed so as to cause as much inconvenience and confusion as possible! The largest of them all (now that Argo Navis has been dismembered) is Hydra, the Watersnake, which is now on view from both the Northern and Southern Hemispheres of the Earth. Its one fairly bright star is Alphard, sometimes nicknamed 'the Solitary One'; it lies more or less in a line with Castor and Pollux in the Twins, and is distinctly reddish. Sir William Herschel (Sir John's father, and discoverer of the planet Uranus) believed Alphard to be variable, but this has not been confirmed. It is of the second magnitude; binoculars will bring out its colour well. Hydra sprawls across a vast area of the sky, but it is remarkably devoid of interesting telescopic objects. Mythologically it represents the Lernæan Hydra which was killed by Hercules during his famous Labours.

Albert Einstein. This month marks the centenary of the birth of one of the greatest scientists of all time: Albert Einstein, who was born at Ulm, in Germany, on 14 March 1879. There can be few people who have not heard of Einstein's theory of relativity, but the greatness of his work has not always been appreciated outside the strictly scientific world. He will always be remembered, and it is not too much to say that in the coming centuries he will be ranked with Newton.

April

Full Moon: 12 April *New Moon:* 26 April

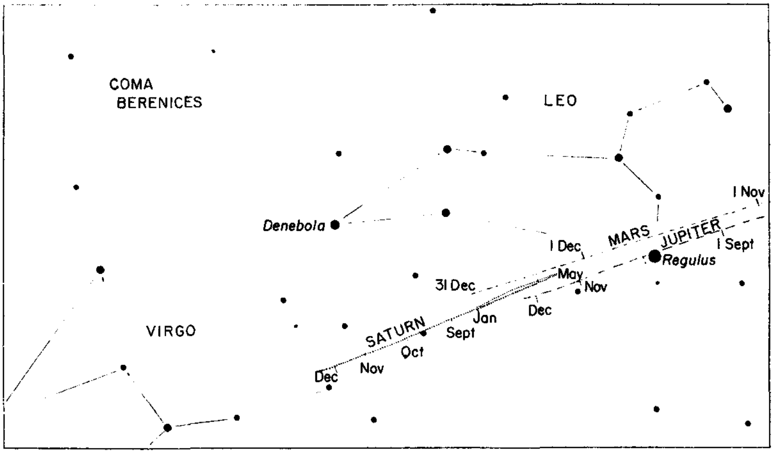
Mercury is at greatest western elongation on 21 April (27 degrees) and will then be visible in the Southern Hemisphere as a morning star. The planet should be well above the horizon to the north of east in the dawn sky, and it grows brighter towards the end of April. Venus is in the same part of the sky, but is farther out from the Sun and easily recognized because of its brilliance.

Venus is still badly placed for northern observers, but in the Southern Hemisphere it rises in the east more than two hours before the Sun (magnitude -3.5 to -3.4).

Mars is a morning star, but is not yet visible in northern latitudes. In the Southern Hemisphere it rises more than an hour before sunrise at the end of March, but the planet is not very bright (magnitude +1.4) and will be difficult to see in the bright sky.

Jupiter is an evening star moving direct in Cancer. The planet is losing its brightness as its distance increases (magnitude -1.9 to -1.7). Jupiter sets at midnight in southern latitudes, but about two hours later at 52 degrees north.

Saturn is an evening star moving retrograde in Leo, and visible to northern observers until about an hour before dawn. In southern latitudes it sets about two hours after midnight (magnitude +0.6 to +0.8).



The diagram shows the path of Saturn during the year, together with parts of the paths of Mars and Jupiter at the end of 1979, to show how these three planets come together at this time in the same part of the sky. Titan is at eastern elongation on 12 and 28 April, and at western elongation on 4 and 20 April.

Pluto is at opposition on 8 April in the northern part of Virgo, at a distance of 2,724 million miles (4,384 million km). Although this is a little more than the distance of Neptune at opposition (see June notes), Pluto is nearer to the Sun than Neptune by about two million miles. The two planets were at the same distance from the Sun on 21 January, but Pluto was then well north of the ecliptic, and about 760 million miles north of the plane of Neptune's orbit. The magnitude of Pluto at opposition is +14.

The discovery of Pluto. Pluto is one of two planets to be located before being actually seen. The other is Neptune, which was discovered in 1846 by Johann Galle and Heinrich D'Arrest, at the Berlin Observatory, as a result of calculations made by the French astronomer, U.J.J. Le Verrier. (John Couch Adams, in England, had reached a similar conclusion somewhat earlier, but no energetic search had been put in hand.) Neptune was tracked down because of its perturbing effects upon Uranus.

Subsequently, it was found that there were still some minor discrepancies in the movements of the outer planets. At the Lowell Observatory in Flagstaff, Percival Lowell began some fresh calculations, and predicted a position for an unknown ninth planet. He carried out a search, but with no success; he died in 1916, and for some time little more was done. At Mount Wilson, in California, Milton Humason used the 100-inch Hooker reflector to photograph an area which had been indicated by W.H. Pickering quite independently; but Humason also had no success, and again the search was abandoned.

It was resumed in 1930 by Clyde Tombaugh, at Flagstaff. This time the result was positive, and in March the new planet was found; it was named Pluto (fittingly enough, since the first two letters are P.L.: Percival Lowell). It had been missed earlier mainly because it was much fainter than Lowell had expected. Ironically, Humason had recorded it twice in 1919, but one image was masked by a star and the other fell upon a tiny flaw in the photographic plate.

However, some curious facts soon came to light. Pluto is not a giant such as Uranus or Neptune; it is certainly smaller than the Earth, and probably smaller than Mars. Its diameter is thought to be no more than 3,600 miles. Assuming normal density (and there is no reason to believe otherwise), Pluto would not be massive enough to cause measurable perturbations in the movements of either Uranus or Neptune—and yet it was by these very perturbations that Pluto was found! Lowell's prediction had been remarkably accurate; so, for that matter, had Pickering's.

This is a major mystery, and as yet it remains unsolved. Possibly Pluto is larger than we think, though most astronomers are sceptical; it is possible, of course, that the accuracy of the position was due to sheer luck, but this would be a truly amazing coincidence. It may well be that there is another planet moving beyond Pluto, though if so it is bound to be very faint and difficult to find.

Pluto's orbit is unlike those of the other planets. It is more eccentric, and is inclined at the unusually high angle of 17 degrees. There have been suggestions that it is an ex-satellite of Neptune which broke free; certainly there is little, if any, difference in size between Pluto and Neptune's remaining large satellite, Triton.

We know little about Pluto except that it has a rotation period of 6.3 days, and has a surface which is probably covered with methane ice. No telescope will show a properly measurable disk, which accounts for the uncertainty in the diameter measurements. Unfortunately, neither of the two Voyagers now on their way to the remote parts of the Solar System will pass anywhere near Pluto.

R Coronæ. Northern Hemisphere observers will be keeping a close watch this month on R Coronæ Borealis, in the little constellation of the Crown, not far from the brilliant Arcturus. Normally, R Coronæ is on the fringe of naked-eye visibility, and is easy with binoculars, but at irregular intervals it drops to minimum brightness, and falls below the range of small telescopes. Not many stars of this type are known, and R Coronæ is the brightest of them. Whether it will 'perform' during 1979 remains to be seen.

Hans Emil Lau. April 16 marks the centenary of the birth of an eminent Danish astronomer, H.E. Lau, who was born in Odense on 16 April, and was educated at Copenhagen. He carried out researches into double and variable stars, and also concentrated upon the planets, particularly Jupiter. He built a private observatory at Horsholm, near Copenhagen. Lau died on 16 October 1918.

May

Full Moon: 12 May *New Moon:* 26 May

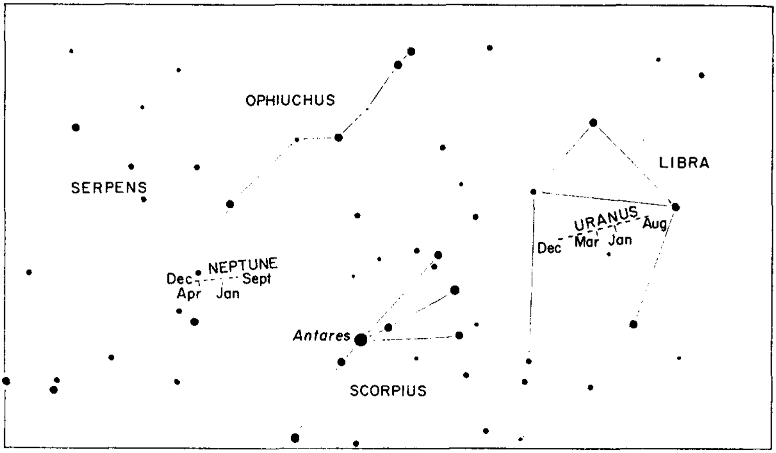
Mercury will not be visible in the Northern Hemisphere, but south of the Equator the planet should be visible in the dawn sky during the first half of May, well to the north of east, and growing brighter.

Venus is a morning star, but is unlikely to be seen in the Northern Hemisphere. Southern observers should see the planet in the east an hour or two before sunrise. Venus passes about a degree south of Mars on 20 May, but this may be difficult to observe in the dawn sky (magnitudes: Venus -3.3; Mars +1.5).

Mars is also a morning star, moving direct from Pisces into Aries during the month (magnitude +1.4 to +1.5). As its elongation from the Sun increases, Mars rises earlier each morning, and by the end of May it rises about an hour before the Sun in the Northern Hemisphere, and about two hours before sunrise in the south. Venus is in the same part of the sky, but is moving more rapidly and passes Mars on 20 May.

Jupiter is an evening star, moving direct in Cancer. The planet sets at midnight in northern latitudes, but about three hours earlier in the Southern Hemisphere (magnitude -1.7 to -1.5).

Saturn is at a stationary point on 10 May and will be seen in Leo some degrees to the east of Regulus (magnitudes: Saturn +0.8 to +0.9; Regulus +1.3). Saturn sets at midnight in southern latitudes, but northern observers will see the planet for more than an hour after this. Titan may be seen at eastern elongation on 14 and 30 May, and at western elongation on 6 and 22 May.



Uranus is at opposition on 10 May in Libra at a distance of 1,643 million miles (2,644 million km). The planet is just visible to the naked eye (magnitude +5.7) and in a small telescope may be seen as a greenish disk. One of the big surprises of 1977 was the discovery that Uranus is surrounded by five thin narrow rings. Photoelectric recordings were made of an occultation of a ninth magnitude star by Uranus at several stations bordering the Indian Ocean. One team of astronomers used a large telescope in a Lockheed aircraft flying at 41,000 feet. The observers were surprised to find that the tracings fell off five times before and after the occultation of the planet. This suggests the presence of five narrow rings—none of them can exceed 10 km in width—encircling the planet at distances varying from 43,000 to 54,000 km from the centre of Uranus. These rings are much too faint to be seen in any telescope, and they do not compare with the larger and denser rings that surround Saturn The circumstances of their discovery are described in more detail by Gordon Taylor in the present *Yearbook.*

The two most famous constellations. Of all the constellations, the two which are best known are probably the Great Bear and the Southern Cross. During May evenings the Bear (Ursa Major) is almost overhead to observers in Britain and the northern United States, while the Cross (Crux Australis) is almost overhead to Australians, New Zealanders and South Africans.

Ursa Major—otherwise known as the Plough or the Big Dipper—has seven chief stars, making up a characteristic pattern which cannot possibly be mistaken. Six of them are around the second magnitude, while the seventh (Megrez) is below the third; ancient observers ranked Megrez as equal to its companions, and there have been many suggestions that it has faded during the past two thousand years, though the evidence is far from conclusive. The most interesting of the Plough stars is probably Mizar (Zeta Ursae Majoris), which has a smaller star close beside it; this star—Alcor—is easy to see with the naked eye on a dark, clear night, and it is hard to understand why the Arabs of a thousand years ago regarded it as a test of visual acuity. Telescopically, Mizar itself is found to be a fine double, with one component distinctly brighter than the other. It was, indeed, the first telescopic double to be discovered (by Riccioli, in 1651).

The two Pointers, Merak and Dubhe, show the way to the Pole Star in Ursa Minor (the Little Bear). Binoculars will show that while Merak is white, Dubhe is distinctly orange in hue. Between the two Bears there sprawls the constellation of the Dragon; in ancient times the pole star was Thuban, or Alpha Draconis, which is below the third magnitude and is therefore much less conspicuous than the present Pole Star.

Crux Australis, unfortunately invisible from Europe and almost all of the United States, is actually the smallest constellation in the whole sky, but it contains four bright stars which make up a shape rather like that of a kite. Three of them are hot and white; Acrux or Alpha Crucis is a wide, easy double. The fourth leading member of the constellation, Gamma Crucis, is orange-red. It has a spectrum of type M, so that it is well advanced in its evolutionary sequence. The colour is easily detectable with the naked eye; binoculars or a telescope will bring it out well.

Despite its small size, Crux is rich in interesting objects. There is, for instance, the lovely open cluster round Kappa Crucis which has been nicknamed the 'Jewel Box', because it contains stars of contrasting colours; there is also the dark nebula known as the Coal Sack, which is a fascinating object telescopically. The Coal Sack is identifiable because it blots out the light of stars beyond; it is not a 'hole in the heavens' as was once suggested. In fact, there is no essential difference between a shining nebula and a dark one. Everything depends upon whether there are any suitable stars in or nearby either to light up the nebulosity or to make it emit light on its own account.

The two Pointers to the Cross are Alpha and Beta Centauri. Alpha, which to the naked eye is outshone only by Sirius and Canopus, is a mere 4.3 light-years from us, and is the closest of the bright stars beyond the Sun (Alpha Centauri C, or Proxima, is slightly nearer, but is a faint Red Dwarf well below naked-eye or binocular range). Beta Centauri, named either Agena or Hadar, is a very luminous and remote star, so that it has no connection with Alpha despite the fact that the two lie side by side in the sky as seen from Earth.

Crux is largely surrounded by Centaurus (the Centaur), and apparently it was included in Centaurus until 1679, when it was separated on a map drawn by an astronomer named Royer. It lies in a rich area, and the 'longer arm' of the pattern indicates the direction of the south celestial pole, which is not marked by any bright star.

June

Full Moon: 10 June *New Moon:* 24 June

Solstice: 21 June

Mercury will be an evening star in the second half of June. The planet is not well placed for northern observers, but in the Southern Hemisphere it will be well above the horizon to the north of west after sunset. The planet is brightest in mid-June, but is then low in the sky. Its brightness decreases as it moves out to eastern elongation in July.

Venus is still a morning star rising about an hour before sunrise to the north of east. Venus is now well north of the Equator and is becoming a more difficult object for southern observers.

Mars is also a morning star and moves from Aries into Taurus in mid-June. By the end of the month it will be found to the south of the Pleiades (see diagram in the July notes). Mars rises about two hours before the Sun at the end of June, but it will be seen to better advantage in the darker sky of the Southern Hemisphere (magnitude +1.5).

Jupiter is still visible until the late evening hours in the north, but sets in the early evening in the Southern Hemisphere. In mid-June, the planet passes between the two stars Delta and Gamma Cancri, and close to the star cluster M44, known as Præsepe, the Beehive. This is the third conjunction with this little group (the others were in November and December last), and later this year Mars will also be in conjunction with M44—see October notes.

Saturn is still an evening star and is now moving direct in Leo. In the Northern Hemisphere the planet sets at midnight in mid-June, but about an hour earlier in southern latitudes. Saturn continues to fade as its distance increases (magnitude +0.9 to +1.1). Titan is at eastern elongation on 15 June, and at western elongation on 7 and 23 June.

Neptune is at opposition on 10 June, when it will be found in the constellation Ophiuchus (see diagram in May notes). The planet is too faint to be seen with the naked eye (magnitude +7.7). The distance of Neptune at opposition is 2,721 million miles (4,378 million km), and its distance from the Sun, which varies very little, is 2,815 million miles. The orbit of Pluto, on the other hand, is very eccentric, and is inclined at more than 17 degrees to the ecliptic. It is therefore possible for Pluto to cross the orbit of Neptune, keeping well above the plane of that orbit, and to have a perihelion distance less than that of Neptune. At this opposition of Neptune, Pluto is about four million miles nearer to the Sun, and it will reach perihelion in 1989.

Neptune. Neptune, the last of the giant planets (so far as we know) is now the outermost of the main members of the Solar System. It is of magnitude 7.7, and is therefore easy to see with binoculars, though admittedly it looks very like a star; if all goes well, it may be bypassed by Voyager 2 in 1989 or 1990. It has been described as the twin of Uranus, but the two worlds are not identical, as Dr. Garry Hunt emphasizes in his article in the present *Yearbook.*

The diameters of remote planets are difficult to estimate with real accuracy, and we are still not sure whether or not Neptune is larger than Uranus. The most recent measurements indicate that it is slightly smaller, but it is definitely more massive.

Its main satellite, Triton, is of planetary size, and is probably larger than Mercury, so that it is not a difficult telescopic object (it was found by the English astronomer William Lassell shortly after the discovery of Neptune itself). It is the only large satellite in the Solar System to have retrograde motion, which indicates that in the remote past something very unusual may have happened; this has been held to support the idea that Pluto too once belonged to the Neptunian system. (The satellites of Uranus are technically retrograde, since they move virtually in the plane of the planet's equator; but their movement is in the same sense as the axial rotation of Uranus.) Neptune's other satellite, Nereid, is extremely small and faint, and moves in an eccentric orbit which is more like that of a comet than a satellite; the motion is direct. It is quite likely that other minor satellites remain to be discovered, and neither can we rule out the possibility that Neptune, like Uranus, has a faint ring-system.

The Scorpion. One of the most magnificent of all the constellations is Scorpio, the Scorpion (sometimes, and rather more correctly, referred to as Scorpius). Its leader is Antares, a red giant of immense size and high luminosity, easily recognizable because it is flanked to either side by a fainter star.

From Britain and the northern United States, Scorpio is never well placed, because it lies well to the south of the celestial equator. During evenings in June, Antares is conspicuous enough as seen from the latitude of London or New York, but from North Scotland it is always so low down that any horizon mist will hide it, while the 'sting' of the Scorpion is virtually invisible. From Southern Hemisphere countries, however, Scorpio is seen in its full glory, and during June evenings it will not be far from the zenith as seen from Australia or South Africa. It is marked by a chain of bright stars, and is extremely rich; binoculars will show several glorious open clusters.

Few constellations bear the slightest resemblance to the objects they are meant to represent. Scorpio is something of an exception, and only a little imagination is needed to picture the form of a scorpion. In mythology, it was a scorpion which crawled out of the ground and fatally stung the hunter Orion, who had boasted that he could kill any creature on Earth. Orion was subsequently brought back to life and placed in the sky; to keep the record straight, the Scorpion too was elevated to celestial rank—but was deliberately put into a position opposite to that of Orion, so that from Europe the two constellations can never be above the horizon at the same time.

Scorpio is in the Zodiac, and can therefore contain planets, though it does not do so in mid-1979. It is bounded to one side of the Zodiacal band by the obscure Libra (the Scales or Balance) and to the other by Sagittarius (the Archer), which contains no first-magnitude star, but whose rich star-clouds indicate the direction of the centre of the Galaxy.

July

Full Moon: 9 July *New Moon:* 24 July

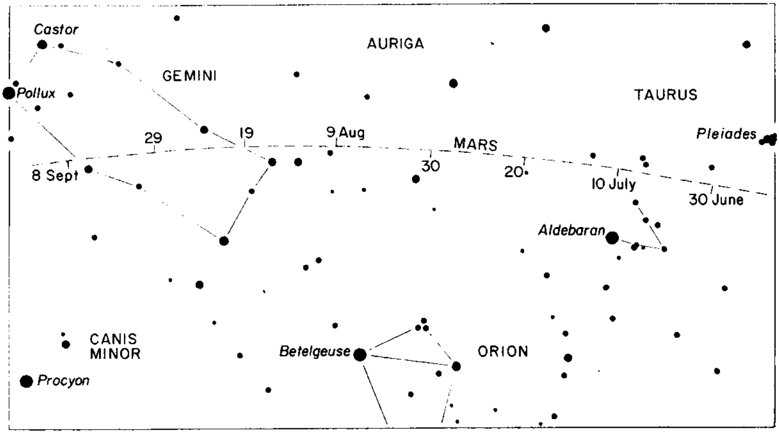
Earth is at aphelion (farthest from the Sun) on 3 July, when its distance will be 94.5 million miles (152.1 million km).

Mercury is at greatest eastern elongation on 3 July (26 degrees) and is then an evening star. The planet is not well placed for northern observers, but will be visible in the Southern Hemisphere to the north of west in the twilight sky. Mercury is not very bright, and must not be confused with Jupiter, which is in the same part of the sky, but is much brighter and farther to the north. Mercury is in inferior conjunction on 31 July.

Venus is now approaching superior conjunction and is not likely to be seen in the Southern Hemisphere. For northern observers it rises to the north of east less than an hour before sunrise.

Mars is a morning star and is now well north in Taurus. On 10 July it passes five degrees north of Aldebaran, and it will be seen that Mars is not as bright as the star (magnitudes: Mars +1.5; Aldebaran +1.1). Mars rises an hour after midnight in northern latitudes, but the sky is not really dark at this time of year. Southern observers should be able to see the planet in a dark sky, since it rises more than an hour before dawn. The diagram overleaf shows the path of Mars from 24 June to 15 September.

Jupiter is an evening star in Cancer, but it is moving towards conjunction and sets an hour after the Sun (northern latitudes)



at the beginning of July, and about an hour later at 35 degrees south. Jupiter is not likely to be seen at the end of the month.

Saturn may still be seen as an evening star, but by the end of July it sets about an hour after the Sun in the Northern Hemisphere. Southern observers will be able to see the planet in a dark sky for an hour or so after dusk (magnitude +1.1). Titan is at eastern elongation on 1 and 17 July, and at western elongation on 9 and 25 July.

The craters of Mercury. Mercury has been known from prehistoric times, though it was not at once realized that the 'evening' and 'morning' objects are one and the same. Early this month is a good time for seeing the planet in so far as Southern Hemisphere observers are concerned, but it is never very prominent, because it always keeps fairly close to the Sun in the sky and can never be seen against a dark background. There must be many people who have never glimpsed the planet at all; a clear sky, free from horizon mist and artificial light, is essential.

Telescopes show little on Mercury. The characteristic phase is obvious enough, but that is all, and before 1974 our knowledge of the surface features was almost nil. The classic map had been drawn by the Greek-born astronomer E.M. Antoniadi, who was renowned for his keen eyesight, and who had the advantage of being able to use the 33-inch refractor at the Observatory of Meudon, near Paris (Antoniadi spent most of his life in France, and became a naturalized Frenchman; he died during the war). Antoniadi charted some features, and gave them names such as Solitudo Hermæ Trismegisti and Solitudo Criophori. However, it was fairly clear that the accuracy of his map was low. Antoniadi also shared in the general view that Mercury has a synchronous rotation, keeping the same hemisphere turned permanently sunward.

Then, in early 1974, came the first fly-by by Mariner 10. Excellent pictures were obtained at this and two subsequent active encounters, and by now we have detailed charts of almost half of the planet's surface. Craters are very much in evidence, and are very similar to those of the Moon, though admittedly there are differences in detail. Ridges and valleys are also seen, and the entire surface is rugged. There is one mountain-ringed area, the Caloris Basin, which has been compared with the lunar Mare Orientale, though unfortunately we have not been able to examine the whole of it; part of the Basin was in darkness each time Mariner flew by.

It has been interesting to compare the actual features with those on Antoniadi's map. To be candid, there is little similarity, and the old names have been abandoned. This was not Antoniadi's fault—and let it be added that his charts of Mars were much closer to the truth.

Mercury, with a diameter of approximately 3,000 miles, is rather larger than the Moon and is considerably more massive. It is also denser, and seems to have a relatively large iron-rich core. There is an appreciable magnetic field, though much weaker than that of the Earth, but the atmosphere is negligible, so that we cannot doubt that Mercury is—and always has been—a sterile world.

During the last century it was thought that there might be another planet still closer to the Sun, and it was named Vulcan; however, recent research has confirmed that Vulcan does not exist. The only planetary body known to approach the Sun to within Mercury's orbit is the tiny asteroid Icarus, though of course many comets do so.

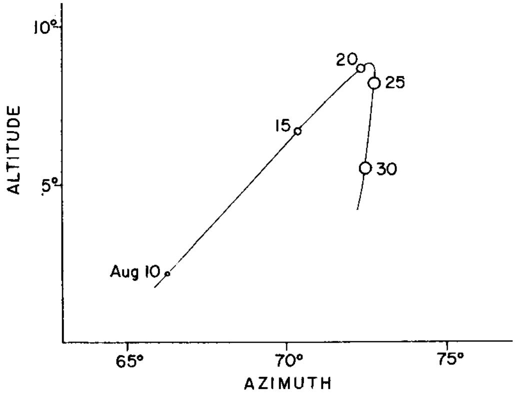
Mars and Aldebaran. In mythology Ares, or Mars, was the God of War, and Martian 'geography' should strictly be known as areography. Certainly the planet is very red in colour, and this month there is a good opportunity to compare it with the orange K-type giant Aldebaran, the 'Eye of the Bull'. The difference in brightness is less than half a magnitude. Most people will consider Mars to be definitely the redder of the two.

Sir Thomas Maclear. Another centenary of this year is that of Maclear, who was born in Ireland and died on 14 July 1879. He trained for medicine, but abandoned this for astronomy, and in 1833 was appointed H.M. Astronomer at the Cape, in South Africa, as successor to Thomas Henderson. Maclear remained there for many years, and retired only nine years before his death. He was a great administrator as well as a first-class astronomer; he carried out much original research, and raised the Cape Observatory to the eminence which it has enjoyed ever since. He was also on particularly friendly terms with Sir John Herschel, who spent several years at the Cape during the 1830s, and who relied heavily upon Maclear for support. Though Maclear was Scottish through and through (and never lost his strong Scottish accent!) he will always be remembered as one of the leaders of astronomy in South Africa.

August

Full Moon: 8 August *New Moon:* 22 August

Mercury is at greatest western elongation on 19 August (19 degrees). This is not a particularly favourable appearance as a morning star, but northern observers may find the planet to the north of east in the dawn. The diagram shows the changes in altitude and azimuth of Mercury on successive mornings when the Sun is 6 degrees below the horizon; this is about 35 minutes before sunrise in August. The changes in brightness are roughly indicated by the size of the circles, and it will be seen that Mercury is brightest *after* the date of western elongation.



Venus is in superior conjunction on 25 August, and will not be visible during the month.

Mars is a morning star moving direct in Taurus north of the figure of Orion. The planet is at its greatest northern declination as it moves into Gemini in early August. Mars rises shortly after midnight in the Northern Hemisphere, but southern observers will not see the planet until about two hours before sunrise (magnitude still +1.5).

Jupiter is in conjunction on 13 August, and will not be seen by southern observers. In northern latitudes, Jupiter appears more rapidly as a morning star, and by the end of August it rises more than an hour before sunrise. The planet is still in Leo (magnitude -1.3).

Saturn is now moving towards conjunction and sets shortly after sunset in the Northern Hemisphere. Southern observers may see the planet at the beginning of August, but by the end of the month it will be lost in the twilight sky.

An annular eclipse of the Sun on 22 August is visible only in the extreme south of the Pacific Ocean. This eclipse occurs when the New Moon is at apogee (farthest from the Earth), and as a result the cone of shadow of the Moon, the umbra, falls short of the Earth by about 15,000 miles, and the apparent diameter of the Moon is 7 per cent less than that of the Sun. This is the last annular eclipse of a series which began in the year 1060. After the lapse of one more Saros, the eclipse of 1 September 1997 will be a partial one.

Pallas. The second largest member of the asteroid swarm comes to opposition on 17 August. With its estimated diameter of 355 miles according to the latest measurements, Pallas is exceeded in size only by Ceres (650 miles). These values are rather higher than used to be thought; however, all the asteroids combined would not make one body as massive as the Moon, so that they may be classed as cosmical débris. Pallas is of magnitude 9, and lies in the constellation of Equuleus; its orbit is inclined at the unusually high angle of 34 degrees. A small telescope will show it, but it looks exactly like a star, and the only safe way to identify it is to observe on several consecutive nights, when Pallas will betray its nature because of its movement against the background of real stars.

The 'Summer Triangle'. This nickname for the triangle of brilliant stars—Vega in Lyra, Altair in Aquila and Deneb in Cygnus—seems to have come into general use (the Editor of this *Yearbook* introduced it, years ago!) but in a way it is inappropriate. True, the Triangle dominates the evening sky during summer in the Northern Hemisphere, but at this time it is winter in the south. Moreover, both Vega and Deneb lie well to the north of the celestial equator, so that as seen from countries such as Australia and South Africa they are always very low down; Altair, much closer to the Equator, can however attain a respectable altitude.

British and North American observers will find Vega almost overhead during August evenings. It is identifiable not only because of its brilliance, but because of its steely blue colour; the spectrum is of type A, and Vega is slightly more than 50 times as powerful as the Sun. Altair, also of type A, is white, and is closer and less luminous; its distance is 16 light-years, so that of the first-magnitude stars only Sirius, Procyon and Alpha Centauri are closer. Like Antares in Scorpio, Altair is flanked to either side by a fainter star (in this case, Gamma Aquilæ or Tarazed, magnitude 3, and Beta or Alshain, approximately magnitude 4), but there should be no confusion, if only because Antares is so noticeably red.

The third member of the Triangle, Deneb in Cygnus, appears the faintest of the trio, but it is much the most luminous, and one recent estimate makes it 60,000 times as powerful as the Sun, in which case its distance is well over 1,000 light-years. Cygnus itself has often been nicknamed the 'Northern Cross', and certainly the X-shape is much more pronounced than in the case of Crux Australis. It was in 1975 that a bright nova appeared in Cygnus; it reached magnitude 1.8, but faded quickly, and was visible to the naked eye for only about a week.

The Star-clouds in Sagittarius. Sagittarius, the Archer, is one of the richest of the Zodiacal constellations. From Britain, it is always very low, and part of it never rises at all, but from Australia, New Zealand and South Africa, it is close to the zenith during evenings in August. The leading star (Kaus Australis) is slightly below the first magnitude, and the constellation has no really definite shape—some people have compared it with a teapot!—but it is distinguished by its magnificent star-clouds, beyond which lies the centre of the Galaxy. We can never see through to the galactic centre, because of the intervening obscuring material, but it has now been established that the distance between the centre and ourselves is rather over 30,000 light-years. Sweeping around Sagittarius with binoculars or a low-power telescope is a rewarding pastime; this is indeed one of the most glorious regions in the entire sky.

John Lamont. Yet another centenary occurs this month. John Lamont was born in Scotland on 13 December 1805, and died on 6 August 1879. When twelve years old he was sent to Ratisbon in Bavaria with a view to becoming a Roman Catholic priest, but he changed over to astronomy, and graduated from Munich. He became Director of the Munich Observatory in 1835. He was concerned with positional astronomy, and also discovered the connection between magnetic activity and the solar cycle.

September

Full Moon: 6 September *New Moon:* 21 September

Equinox: 23 September

Mercury is in superior conjunction on 13 September, and will not be visible during the month.

Venus is theoretically an evening star but is not likely to be seen as yet. It is now on the far side of its orbit, and its motion is slow, so that it may be some weeks before it can be seen in the western sky at sunset.

Mars is a morning star moving direct in Gemini. It passes six degrees south of Pollux on 14 September, and at the end of the month moves into Cancer. The distance of Mars is now decreasing more rapidly, and this causes an increase in the brightness of the planet (magnitude +1.5 to +1.4). Mars rises about midnight in the Northern Hemisphere, but in southern latitudes about three hours later.

Jupiter is a morning star moving direct in Leo. On 26 September it is in close conjunction with Regulus, passing only 0.3 degrees north of the star. The actual conjunction is not likely to be seen, but Jupiter will be found very close to Regulus on the mornings of the 26 and 27 September. This event will be difficult to see at southern stations, where the planet rises only about an hour before the Sun. Northern observers are more favourably placed, and should be able to see the star and Jupiter in a dark sky before dawn. This single conjunction of Jupiter and Regulus may be compared with the triple conjunction of Mars with the same star (see November notes). (Magnitudes: Jupiter −1.4; Regulus +1.3.)

Saturn is in conjunction with the Sun on 10 September, and after this date will begin to appear as a morning star. By the end of September, Saturn rises more than an hour before the Sun in northern latitudes, but it will not yet be visible in the Southern Hemisphere. The planet is still moving direct in Leo (see diagram in the April notes) and the rings are presented to the Earth at a very narrow angle—about two degrees. The orbits of the inner satellites of Saturn lie close to the plane of the rings, so that these are also seen almost edge-on. As a result these satellites, like those of Jupiter, can undergo eclipses, occultations and transits, but with the exception of Titan these are not readily observed in small telescopes. These phenomena began with occultations and transits of the innermost satellites at the end of 1977, but the orbit of Titan is so large that conditions are much more critical. Eclipses and other phenomena of Titan begin in October 1979, but will last for only a few months.

The approach of Mars. Mars is now brightening up, and by the end of the month will be approximately equal to Regulus. The next opposition will occur on 25 February 1980, when Mars will be in Leo. However, Southern Hemisphere observers will not enjoy very good views, for two reasons. First, Mars is well north of the celestial equator; secondly, this is an aphelic opposition, and the minimum distance from Earth will be greater than 60 million miles—as against less than 35 million miles for an opposition which takes place near Martian perihelion.

It is also true to say that Mars is never an easy object to study with a small telescope, and the beginner who hopes to see vegetation tracts and canals is doomed to disappointment! Indeed, the pictures sent back by the Mariner and Viking probes have confirmed that the canal network, publicized earlier in this century by men such as Percival Lowell, simply does not exist; and we are now quite certain that the dark regions are not plant-filled sea-beds.

One of the main objects of the Viking programme was to find out whether life on Mars existed at all. The results cannot be said to be absolutely conclusive, but no definite evidence for life has been found, and most astronomers (though not all) now incline to the view that the planet is sterile. On the other hand, there can be little doubt that the features shown by the probes, and which look like dry riverbeds, really *are* dry riverbeds; in which case, Mars must have had surface water and a thicker atmosphere in the past.

Another revelation has been that the two polar caps are not alike. That in the north is made up chiefly of water ice, with a thin seasonal overlay of solid carbon dioxide, but that in the south may be a mixture of water ice and CO_2 ice. The great volcanoes of the Tharsis region play a major role in Martian meteorology; wind speeds may be quite high, though in that thin atmosphere they have little force, and dust-storms are much commoner than used to be thought.

Mars is not the sort of world we believed it to be before the flight of Mariner 4 in 1965. Yet, though we have learned so much, there is still a great deal that we do not know, and the results from future probes will be awaited with the keenest interest. At the next opposition, the northern hemisphere of the planet will be tilted towards us, as was also the case in 1977-8, but during the autumn of 1979 telescopes of the size owned by average amateur astronomers will show very little.

The square of Pegasus. During September evenings one of the main features of the sky is Pegasus, the Flying Horse—in mythology, ridden by the hero Bellerophon in his attack on the hideous fire-breathing Chimæra. The four leading stars make up a square, but the brightest of them—Alpheratz—has been officially transferred into the adjacent constellation of Andromeda, and has become Alpha Andromedæ instead of Delta Pegasi. There seems no logical reason for this, since it so clearly belongs to the Pegasus pattern.

The other three stars of the Square are Markab, Scheat and Algenib. Of these, Scheat is orange in colour, and is somewhat variable, though the magnitude never becomes as bright as 2 or as faint as 3; there is a very rough period of about 38 days. Algenib, the faintest of the stars in the Square, is actually the most luminous, and lies much farther away.

Leading off from Pegasus is the line of stars marking Andromeda. The most celebrated object here is the Great Spiral, M.31, which is a galaxy considerably larger than our own, and containing more than our quota of 100,000 million stars. Southern Hemisphere observers will be lucky to see it with the naked eye, because it is always so low down, but Britons and North Americans should have no difficulty in glimpsing it as a misty patch, and binoculars show it easily. Unfortunately, it is placed at a sharp angle to us, so that the full beauty of its spiral form is lost. At its distance of 2,200,000 light-years, M.31 is the most remote object which can be clearly seen with the naked eye.

October

Summer Time in Great Britain and Northern Ireland ends on 28 October.

Full Moon: 5 October *New Moon:* 21 October

Mercury is at greatest eastern elongation on 29 October (24 degrees) and is an evening star throughout the month. It is not likely to be seen in the Northern Hemisphere, but is well placed for southern observers. The planet is brightest at the beginning of the month, but at a greater altitude in the south-west towards the end of October.

Venus is an evening star but is now south of the Equator and is not likely to be seen in northern latitudes. In the Southern Hemisphere, it sets more than an hour after the Sun by the end of October (magnitude −3.4 to −3.3).

Mars is a morning star in Cancer, but towards the end of the month it moves into Leo. On 8 October, Mars is north of the fourth magnitude star Delta Cancri, and quite close to the star-cluster M44 (Præsepe, the Beehive). The planet continues to grow brighter (magnitude +1.4 to +1.1) and rises at midnight in northern latitudes. Southern observers will find the planet Mars to the north of east, rising about three hours before the Sun. The path of Mars at this time is shown in the diagram in the January notes.

Jupiter is a morning star in Leo, still close to Regulus, but moving to the east, away from the star. At northern stations, the planet may be seen in a dark sky, rising about an hour after midnight at the end of October. Southern observers will find observation more difficult, since the planet does not rise until dawn. Jupiter continues to grow brighter (magnitude –1.4 to –1.5).

Saturn is also a morning star and moves from Leo into Virgo during the month. Conditions are most favourable in the Northern Hemisphere, and by the end of the month Saturn rises about four hours before the Sun, and may be seen in a dark sky. On 27 October, the plane of the rings passes through the Earth, so that they will be presented edge-on to the observer. From this date, for several months, the rings will be invisible in all but the largest telescopes, because the Sun will still be shining on the south side of the rings, while the Earth sees only the dark northern side. In March 1980, the ring-plane will pass through the Sun, and the rings will be visible once more, both Sun and Earth being then on the north side. There can be only one passage of the ring-plane through the Sun, but it can pass through the Earth either once or three times. There will be two further ring-passages through the Earth in 1980, giving another period of invisibility, but after this both Earth and Sun will remain on the north side of the rings for the next fifteen years.

The edgewise presentation of Saturn's rings. During edgewise ring-presentation Saturn loses its beauty, but not its interest. Though they are so extensive (169,000 miles from one side to the other) the rings are very thin, which accounts for their disappearance. The thickness has been variously estimated, but 10 miles may be fairly close to the truth.

If all goes well, something may be learned from the Pioneer 11 probe, which bypassed Jupiter in December 1974 and is scheduled to rendezvous with Saturn in 1979. The probe will be put into a path which will take it outside the main ring system, and whether any pictures will be obtained is somewhat dubious, but the possibility is there. Next will come Voyager 1, in November 1980, which should certainly produce spectacular results. Voyager 2 will follow in 1981.

Ceres. The first discovered and largest of the asteroids, Ceres, comes to opposition this month, in Cetus, but it is below the seventh magnitude, and so is below naked-eye visibility. In fact, the only asteroid to be visible without optical aid is Vesta, which is also in Cetus at the present moment; but this year the magnitude will not exceed 6.6.

Ceres, with its diameter of 650 miles, is the senior member of the swarm. It is larger than previously believed (the previous diameter estimate was 427 miles), but its gravitational pull is so weak that it can retain no vestige of atmosphere.

There is an interesting story connected with its discovery. In the 1770s, Johann Elert Bode, a famous German astronomer, popularized a 'law' previously announced by Titius; it is usually called Bode's Law, and gives a mathematical relationship between the distances of the various planets from the Sun. It indicated that there should be an extra planet between the orbits of Mars and Jupiter, and near the turn of the century several astronomers, headed by Johann Schröter and the Baron Franz Xavier von Zach, undertook a systematic search for it. Ironically, they were forestalled; Piazzi at Palermo, in Sicily, was compiling a star-catalogue when he detected a moving object which subsequently proved to be moving at just the right distance. This was Ceres. However, the 'Celestial Police', as they were nicknamed, did find three more asteroids within the next few years (Pallas, Juno and Vesta), after which no more came to light until an amateur named Hencke found No.5, Astræa, in 1845.

There has been much discussion as to the validity, or otherwise, of Bode's Law, but it breaks down completely for Neptune and Pluto, and there are many astronomers who now regard it as nothing more than an interesting coincidence.

Fomalhaut. Fomalhaut, in the small constellation of the Southern Fish, is the most southerly of the first-magnitude stars to be visible from Britain. It lies below the Square of Pegasus, not far above the southern horizon; observers in North Scotland will probably not see it at all. However, from Australia or South Africa, Fomalhaut is almost overhead during October evenings, and it is bright enough to be conspicuous. The apparent magnitude is 1.2, and the colour is white (spectral type A).

Fomalhaut is relatively close; the distance is 23 light-years, and the luminosity is 15 times that of the Sun. The 'absolute magnitude' is 1.9. This means that if it could be seen from a standard distance of 10 parsecs (32.6 light-years), the apparent magnitude of Fomalhaut would be 1.9—approximately the same as that of the Pole Star. Yet if Rigel or Deneb could be seen from this distance, their magnitudes would be above -7, and they would be capable of casting shadows!

Fomalhaut is the only bright star in its area; the Southern Fish contains nothing else of importance, and there are no telescopic objects in it likely to be of interest to the amateur observer.

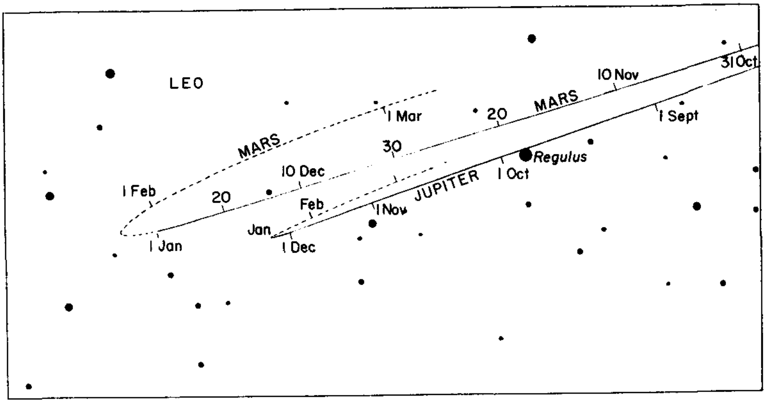
November

Full Moon: 4 November *New Moon:* 19 November

Mercury is in inferior conjunction on 20 November, but moves out rapidly from the Sun to become a morning star. Northern observers should look for the planet in the last week of November, when it will be a few degrees above the south-eastern horizon in the dawn sky.

Venus is an evening star, and conditions for observing this planet improve towards the end of November. Venus is well south of the Equator, and is most favourably placed for southern observers. By the end of the month, Venus sets an hour after the Sun in the Northern Hemisphere, but remains visible for another hour in southern latitudes (magnitude -3.3).

Mars is a morning star, and in northern latitudes it rises shortly before midnight, in southern latitudes about two hours later. Mars is still moving direct in Leo, and on 17 November it passes 1.6 degrees north of Regulus. This is the first of three conjunctions of the planet with this star (the others are in March and April next year), and although Mars is not yet at its brightest, it will be seen to be brighter than Regulus (magnitudes: Mars +0.9; Regulus +1.3). The path of Mars at this time is shown in the April notes, but the diagram below is on a larger scale and shows the paths of Mars and Jupiter continued into 1980 to indicate how the loops in the two paths cause the triple conjunctions of Mars with Regulus and with Jupiter. The loop in the path of Mars is much larger than that shown by Jupiter because Mars is much nearer to the Earth.



Jupiter is a morning star in Leo, and rises at midnight in northern latitudes, and about an hour later for southern observers. The planet is easily recognized, since it is the most brilliant object in the morning sky (magnitude −1.5 to −1.7). It is interesting to note the line of planets in order—Mars, Jupiter, Saturn, Uranus and Neptune—from west to east. Their apparent positions are given in the table on page 74. At the beginning of November, Mars, Jupiter and Saturn are all morning stars (west of the Sun), while Uranus and Neptune have not yet reached conjunction and are still east of the Sun as evening stars.

Saturn is moving direct in Virgo and rises about an hour after Jupiter. By the end of the month it will be seen south of Denebola, the second magnitude star in the tail of the Lion, but Saturn is nearly a magnitude brighter (+1.4 to +1.3). Titan is at eastern elongation on 6 and 22 November, and at western elongation on 14 and 30 November.

Titan. With the rings edgewise-on, this is a good time to study the satellite system of Saturn. Pride of place must go to Titan, which moves round the planet at a mean distance of 760,000 miles in a period of 15 days, 22 hours, 41 minutes. A small telescope will show it, since the mean magnitude is only slightly below 8.

Titan is probably the largest satellite in the Solar System (its only rival is Triton, the senior attendant of Neptune). The diameter has recently been estimated as 3,600 miles, so that in size Titan is intermediate between Mars and Mercury; however, its density may be only about 1.3 times that of water, so that the mass is much less than that of either Mars or Mercury. The escape velocity is about 1½ miles per-second.

In one way Titan is unique: it is the only satellite in the Solar System known to possess an appreciable atmosphere, and it now seems that the ground atmospheric pressure is of the order of 100 millibars—ten times that at the surface of Mars. Clouds may well exist, and there have been very recent suggestions that the atmosphere may be even denser than we have thought, though it is quite unlike our own and is quite unbreathable. (Moreover, Titan is bitterly cold, and no life of our kind can be expected there.)

As yet we cannot be positive about the internal constitution of Titan, but there may be a wet, rocky mantle which is in turn overlaid by a solution of ammonia and water; finally, there is a thin ice and methane crust. It does not sound attractive, and from our point of view it is not. All the same, there is no definite reason why landings on Titan should not take place eventually.

On 13 November 1980, the probe Voyager 1 is scheduled to bypass Titan at a distance of less than 5,000 miles, and to send back both pictures and general information. If it fails, then Voyager 2 will be sent past Titan in August 1981. The disadvantage here is that if Voyager 2 has to survey Titan, it will be unable to go on to make a rendezvous with Uranus in January 1986; for technical reasons it is impossible to 'take in' both Titan and Uranus with a single vehicle. Therefore, astronomers are devoutly hoping that Voyager 1 will function successfully!

The celestial poles. There can be no difficulty in locating the north pole of the sky, because the second-magnitude Polaris lies within one degree of it. Things are less easy in the south, since the south celestial pole lies in a very barren area—in the constellation of Octans, the Octant. The nearest naked-eye star is Sigma Octantis, which is only of the fifth magnitude, and so is hidden by moonlight or by the slightest mist.

As has been noted, the longer axis of the Southern Cross points to the pole, but a more useful method is to locate both the Cross and the bright star Achernar, in Eridanus, the River. (Like the Cross, Achernar is invisible from Europe and the United States.) The pole lies approximately midway between the two. During November evenings, Australian and South African observers will find Achernar almost overhead, but this means that the Cross is at its very lowest, skirting the southern horizon.

Because of precession, the positions of the celestial poles shift slowly. When the Egyptians were building their Pyramids, the north polar star was Thuban or Alpha Draconis; in 12,000 years from now it will be the brilliant Vega. There will eventually come a time when Canopus will be close to the south celestial pole, but the shift is too gradual to be noticed by the casual observer over a lifetime, and those who read this *Yearbook* and who live in southern latitudes must resign themselves to making do with Sigma Octantis!

December

Full Moon: 3 December *New Moon:* 19 December

Solstice: 22 December

Mercury is at greatest western elongation on 7 December (21 degrees) and is then a morning star. It should be favourably placed in the Northern Hemisphere in the first half of December. Observers should look for Mercury a few degrees above the south-eastern horizon in the dawn sky.

Venus has now moved out far enough from the Sun to be more readily visible as an evening star. The planet sets nearly two hours after sunset in the south-west, and will reach its greatest elongation from the Sun in April next (magnitude -3.4).

Mars is still a morning star to the south of the figure of Leo. It is growing rapidly brighter (magnitude +0.7 to +0.2) as it approaches opposition in February 1980. On 13 December, Mars passes 1.7 degrees north of Jupiter, and this is the first of a series of three conjunctions of these two planets. The next two occur in March, when both are moving retrograde, and in May when both are once more moving direct. This rare event is due to the fact that the two planets are at opposition at almost the same time, only twelve hours separating the oppositions of Jupiter and Mars on 24-25 February next.

Jupiter is a morning star, rising at about the same time as Mars, the two planets being in the south of Leo. The conjunction of Mars and Jupiter on 13 December is shown in the diagram in the November notes. Jupiter is two magnitudes brighter than

Mars (–1.7 to –1.9) which means that it is more than six times as bright. Jupiter reaches a stationary point on 27 December, and after this date its motion will be retrograde.

Saturn is a morning star in Virgo and rises at midnight in mid-December in northern latitudes, and a little later in southern stations. Saturn continues to grow brighter as it moves towards opposition in March next (magnitude +1.3 to +1.1). Eastern elongation of Titan on 8 and 24 December, western elongation on the 16th.

Triple conjunctions of planets. The conjunctions of Mars and Jupiter mentioned above are sufficiently rare to deserve further comment. There were triple conjunctions of these two planets in 1790 and in 1837, but none have been traced since then. The interval of 47 years would seem to be an important factor. Conjunctions of Mars and Jupiter will occur on the average at an interval of 816.4 days, but this figure will vary widely because of the eccentric nature of the orbit of Mars. Nearly all of these conjunctions will be single events, and the triple conjunction can only occur when both planets are near opposition. Now 22 synodic periods of Mars and 43 of Jupiter are almost equal to 47 years, and this is the smallest interval at which these triple conjunctions can occur, provided that other conditions are suitable. It is significant that all three of these events occur in February-March, when Mars is near aphelion, and is then farther away from the Earth and is moving more slowly.

In 1884, and in 1933, the two planets came close to the critical conditions, but in both cases there was only one conjunction. Similar rules apply to other pairs of planets, but may be even more restrictive. Thus, there was a triple conjunction of Jupiter and Saturn in 1683, but this did not happen again until 1940, when both planets were at opposition on the same day, 3 November. There will be a repetition of this triple conjunction in 1981 when the two oppositions will again be close together.

Betelgeux. Orion dominates the December evening sky, and since it is crossed by the celestial equator it may be seen from every inhabited part of the Earth. Of its two leaders, Rigel is particularly luminous (about 60,000 Sun-power according to one recent estimate) and is pure white. Betelgeux—alternatively spelled Betelgeuse or Betelgeuze—is quite different. Its orange-red hue is obvious at a glance; the spectrum is of type M, and Betelgeux is a typical example of a Red Giant. Its diameter is about 250 million miles, which is big enough to contain the whole orbit of the Earth round the Sun. Like many Red Giants, it is variable; sometimes it may challenge Rigel, while at others (as in early 1978) it is more nearly comparable with Aldebaran. Its changes in brightness are slow, but may be followed with little difficulty by the patient observer.

The Star of Bethlehem. This year Venus is in the west after sunset, and inevitably the old question will be repeated: 'Was Venus the Star of Bethlehem?' The answer must be in the negative—if only because Venus is visible regularly, and could not possibly have deceived the 'Wise Men' or anyone else.

It has been suggested that the Star was a comet, and certainly Halley's Comet did return some years before the birth of Christ, but the description does not fit, and of course the comet would have been on view for some time. We can certainly discount the theory that the Star was caused by a close conjunction of two planets. This idea is revived with monotonous regularity, but it has been shown to be completely out of court.

A supernova? We would have expected to find references to it in other places as well as the Bible. An ordinary nova has also been proposed, and there does seem to have been one around 4 B.C.; but our information about the Star of Bethlehem is so scanty that the problem will probably never be cleared up.

Eclipses in 1979

In 1979 there will be two eclipses of the Sun and two of the Moon.

(1) *A total eclipse of the Sun* on 26 February, the line of totality entering the United States south of Seattle, passing into Canada through Winnipeg, and crossing Hudson Bay to end in Greenland. A partial eclipse will be visible throughout Canada and the United States and the North Atlantic. In Scotland, Ireland and the west of England, only the beginning of the eclipse will be visible at sunset. The eclipse will be total at Winnipeg for 2 min. 14 sec.

	Mag.	Begins	Max.	Ends
Winnipeg	100	15^h36^m	16^h48^m	18^h03^m
Seattle	99	15 15	16 18	17 26
Los Angeles	78	14 56	15 59	17 08
New York	68	15 59	17 16	18 31

All times are G.M.T. The magnitude is given as a percentage of the Sun's diameter.

(2) *A partial eclipse of the Moon* on 13 March will be visible in the British Isles and South Africa. The beginning of the eclipse may be seen in Australia and the end in north-eastern parts of North America. The eclipse begins at 19^h 29^m G.M.T. and will reach a maximum at 21^h 08^m when 86 per cent of the Moon's disk will be darkened by the Earth's shadow. The eclipse ends at 22^h 47^m

(3) *An annular eclipse of the Sun* on 22 August will be

visible only in the extreme south of the Pacific Ocean and in Antarctic regions. A partial eclipse may be seen in parts of South America south of 20 degrees south latitude.

(4) *A total eclipse of the Moon* on 6 September, visible in Australia and New Zealand. The early stages may be seen in most of North and South America. The eclipse begins at $9^h\ 18^m$ and becomes total at $10^h\ 31^m$ G.M.T. Totality lasts until $11^h\ 17^m$ and the eclipse ends at $12^h\ 30^m$

Occultations in 1979

In the course of its journey round the sky each month, the Moon passes in front of all the stars in its path and the timing of these occultations is useful in fixing the position and motion of the Moon. The Moon's orbit is tilted at more than five degrees to the ecliptic, but it is not fixed in space. It twists steadily westwards at a rate of about twenty degrees a year, a complete revolution taking 18.6 years, during which time all the stars that lie within about six and a half degrees of the ecliptic will be occulted. The occultations of any one star continue month after month until the Moon's path has twisted away from the star but only a few of these occultations will be visible at any one place in hours of darkness.

Only four first-magnitude stars are near enough to the ecliptic to be occulted by the Moon; these are Regulus, Aldebaran, Spica, and Antares. The occultations of Aldebaran, which began in 1978, continue throughout the year, and will be visible in the Northern Hemisphere. A series of occultations of Regulus will begin in November, the first of these events being visible in New Zealand and the Antarctic regions. Occultations of the planets Mercury, Venus, Saturn and Jupiter are also predicted during the year.

The value of the exact timing of an occultation is shown by the results which have been obtained from observations of occultations of radio stars by the Moon, and predictions of such events are now routine. Occultations of stars by planets and some of their satellites are also predicted and observations of these give information about the orbits, sizes and atmospheres. The discovery of the rings of Uranus in March 1977 was the unexpected result of observations of an occultation of a faint star by Uranus (see May notes).

Comets in 1979

The appearance of a bright comet is a rare event which can never be predicted in advance, because this class of object travels round the Sun in an enormous orbit with a period which may well be many thousands of years. There are therefore no records of the previous appearances of these bodies, and we are unable to follow their wanderings through space.

Comets of short period, on the other hand, return at regular intervals, and attract a good deal of attention from astronomers. Unfortunately they are all faint objects, and are recovered and followed by photographic methods using large telescopes. Most of these short-period comets travel in orbits of small inclination which reach out to the orbit of Jupiter, and it is this planet which is mainly responsible for the severe perturbations which many of these comets undergo. Unlike the planets, comets may be seen in any part of the sky, but since their distances from the Earth are similar to those of the planets their apparent movements in the sky are also somewhat similar, and some of them may be followed for long periods of time.

The number of comets under observation in any one year is much greater than is generally supposed. The following table compares the numbers of newly discovered comets, successfully predicted returns of periodic comets and comets being followed from previous years:

	1974	1975	1976	1977
New discoveries	5	13	5	8
Predicted and recovered	4	4	6	11
Still under observation	14	9	16	13
	—	—	—	—
	23	26	27	32

In 1979, the following periodic comets are expected to return to perihelion:

Comet Tuttle-Giacobini-Kresák has the short period of 5.6 years, and owes its triple name to three independent discoveries in 1858, 1907 and 1951. Since that time the comet has been seen at alternate returns in 1962 and 1973, and although it is due to return in December 1978, conditions are most unfavourable.

Comet Van Biesbroeck was discovered at Yerkes Observatory in 1954 and was observed again in 1966. This comet has a period of 12.4 years, and the large orbit has its perihelion well outside the orbit of Mars, and its aphelion between the orbits of Jupiter and Saturn. Its perihelion passage is predicted for December 1978.

Comet Jackson-Neujmin was discovered in 1936 and had been considered lost until it was recovered by Kowal in 1970. The comet has a period of 8.4 years, and the somewhat uncertain orbit indicates a return to perihelion in December 1978.

Comet Shajn-Schaldach was discovered independently in 1949 by Mrs. P. Shajn at the Simeis Observatory in the Crimea, and by Robert D. Schaldach of the Lowell Observatory in Arizona. This comet also was lost until its recovery by C. Kowal at Palomar in 1971. It has a period of 7.3 years, and should return to perihelion in January.

Comet Giacobini-Zinner was first seen in 1900 and has made nine appearances, the last being in 1972. The orbit has a period of 6.5 years and the high inclination of 32 degrees. It is this comet that is responsible for the Draconid meteor shower sometimes seen in October. Perihelion passage is expected in February.

Comet Holmes was discovered in 1892 and seen again in 1899 and 1906. For many years it was regarded as lost, but a new prediction resulted in its recovery in 1964. When first discovered, Comet Holmes was of naked-eye brightness, but it is now a very faint object. It has a period of 7.1 years, and is expected to return in February.

Some at least of these comets will have been recovered during 1978, but there are several others that can be observed every year, generally when they are well placed at opposition.

Comet Schwassmann-Wachmann (1) has a large and nearly circular orbit which lies entirely between the orbits of Jupiter and Saturn. Although the period is sixteen years, it is visible each year and is notable for its sudden outbursts of brightness. Normally of magnitude 18 it has been known to increase to magnitude 10.7—more than 800 times as bright. Similar behaviour, though less spectacular, is also shown by some other comets.

Comet Encke has the smallest known orbit, with a period of only 3.3 years, and with modern large telescopes it can be observed even at aphelion.

Comet Gunn was discovered at Palomar in 1970 and has a period of 6.8 years. The orbit is noticeably eccentric, but observations are made each year.

Comet Smirnova-Chernykh and *Comet Gehrels (3)* were both discovered in 1975 and have periods of 8.5 and 8.1 years respectively. The eccentricity of both orbits is very small, and both can be observed right round their orbits.

Meteors in 1979

Meteors ('shooting stars') may be seen on any clear moonless night, but on certain nights of the year their number increases noticeably. This occurs when the Earth chances to intersect a concentration of meteoric dust moving in an orbit around the Sun. If the dust is well spread out in space, the resulting shower of meteors may last for several days. The word 'shower' must not be misinterpreted—only on very rare occasions have the meteors been so numerous as to resemble snowflakes falling.

If the meteor tracks are marked on a star map and traced backwards, a number of them will be found to intersect in a point (or a small area of the sky) which marks the radiant of the shower. This gives the direction from which the meteors have come.

The following table gives some of the more easily observed showers with their radiants; interference by moonlight is shown by the letter M.

Limiting dates	*Shower*	*Maximum*	*R.A.*	*Dec.*	
Jan. 1-6	Quadrantids	Jan. 4	$15^h 28^m$	+50°	
Mar. 14-18	Corona Australids	Mar. 16	$16^h 20^m$	−48°	M
April 20-22	Lyrids	April 21	$18^h 08^m$	+32°	
May 1-8	Aquarids	May 5	$22^h 24^m$	+00°	
June 17-26	Ophiuchids	June 20	$17^h 20^m$	−20°	
July 15-Aug. 15	Delta Aquarids	July 25	$22^h 36^m$	−17°	
July 15-Aug. 20	Pisces Australids	July 31	$22^h 40^m$	−30°	
July 15-Aug. 25	Capricornids	Aug. 2	$20^h 36^m$	−10°	
July 27-Aug. 17	Perseids	Aug. 12	$3^h 04^m$	+58°	M
Oct. 15-25	Orionids	Oct. 20	$6^h 24^m$	+15°	
Oct. 26-Nov. 16	Taurids	Nov. 8	$3^h 44^m$	+14	M
Nov. 15-19	Leonids	Nov. 17	$10^h 08^m$	+22°	
Dec. 9-14	Geminids	Dec. 14	$7^h 28^m$	+32°	
Dec. 17-24	Ursids	Dec. 22	$14^h 28^m$	+76°	

M=moonlight interferes

Minor Planets in 1979

Although many thousands of minor planets (asteroids) are known to exist, only about 2,000 of these have well-determined orbits and are listed in the catalogues. Most of these orbits lie entirely between those of Mars and Jupiter. All of these bodies are quite small, and even the largest can only be a few hundred miles in diameter. Thus they are necessarily faint objects, and although a number of them are within the reach of a small telescope few of them ever reach any considerable brightness. Of these, the most important are the 'big four', Ceres, Pallas, Juno, and Vesta. Vesta can occasionally be seen with the naked eye, and this is most likely to occur at a June opposition, when Vesta is at perihelion. In 1979, Vesta is at opposition on 3 November in Cetus, but only reaches magnitude +6.6. Ceres is also in Cetus at its opposition on 6 October, when its magnitude is +7.2. There is no opposition of Juno during the year, and at its brightest in December it only reaches magnitude +7.7. Pallas is even fainter (magnitude +9.1) at its opposition on 17 August, well north of the ecliptic in Equuleus.

Most minor planets have periods less than eight years, although there is one important group, the Trojans, which have periods similar to that of Jupiter. An entirely different kind of orbit has been calculated for an object found by C. Kowal at Palomar in October 1977. In the course of a search for further Trojans, Kowal detected an object moving remarkably slowly in Aries. Further observations enabled a preliminary orbit to be calculated, and this object, provisionally known as 1977 UB and now christened Chiron, has proved to have an orbit which takes it from just inside that of Saturn out almost as far as Uranus. Kowal himself gives full details in his article in the present *Yearbook*.

Some Events in 1980

ECLIPSES

In 1980 there will be two eclipses, both of the Sun.

16 February—a total eclipse of the Sun, visible in Africa and southern Asia.

10 August—an annular eclipse of the Sun, visible in Hawaii, the West Indies and South America.

THE PLANETS

Mercury may best be seen in northern latitudes at eastern elongation (evening star) on 19 February, and at western elongation (morning star) on 1 August. In the Southern Hemisphere the best dates are 2 April (morning star) and 11 October (evening star).

Venus will be an evening star until inferior conjunction on 15 June, and a morning star for the rest of the year. Greatest eastern elongation on 5 April, greatest western elongation on 24 August.

Mars is at opposition on 25 February in Leo, but will then be at aphelion.

Jupiter is at opposition on 24 February, also in Leo and close to Mars. Conjunction occurs on 13 September.

Saturn is at opposition on 14 March on the borders of Leo and Virgo, and will be in conjunction on 23 September.

Uranus is at opposition on 14 May in Libra.

Neptune is at opposition on 12 June and is still in Ophiuchus.

Pluto is at opposition on 10 April on the borders of Virgo and Boötes.

PART TWO

Article Section

The Shoulders of the Giants

R. MADDISON

In these days of post-Apollo euphoria and sophisticated high technology one might be forgiven for believing that scientists and technologists have the whole thing sewn up. There seems to be no real problem that is not easily soluble using the right computer programme. We know the laws of Natural Science to such high accuracy and can apply them to such wide ranges of conditions and properties that there seems to be no barrier beyond which we cannot go.

The last time that this attitude was prevalent was the end of the nineteenth century, when black-coated 'men of science' would prognosticate in a rather pompous way about the behaviour of things and would apply their recently acquired knowledge of the ultimate atomic structure of matter to a wide range of problems, with apparent success. But then in 1897, J.J. Thomson discovered the electron, and upset the whole applecart. Science has never been quite the same since that time.

If one looks further back into the history of science one finds that the whole story is one of adopting arrogant postures, which are subsequently demolished by a few simple key observations. There is often an almost overbearing egoism, an over-confidence in abilities, a readiness to condemn predecessors out of hand, and a refusal to recognize the relative unimportance of terrestrial life in the overall scheme of things.

An oversimplified example is the development of our understanding of the structure of the Universe. Originally the surface of the Earth, and of course mankind on it, was regarded as the centre of everything and the most important part of the

Universe. Everything else was, therefore, of secondary importance and rotated around the Earth. As measuring accuracy increased, it was realized that such a geocentric picture was too complex to be true, and that a better way of looking at it was to regard the Sun as central with the Earth in orbit around it. This apparent change in the overall significance of Man, moving him away from the central hub of the Universe to a position of much less importance, caused considerable upset and stimulated the dogmatists into trying to assert their views by violence.

This period may be identified as the time when the scientific approach began to emerge and the reasoning scientific method began to form. Observational accuracy was improved, and hypotheses were put forward to account for observed phenomena. Further observation, based on prediction from the hypotheses, led to the formation of a theory, and the theory hardened with accumulated experience into Law. (The distinction between such scientific Law and civil Law is, of course, that civil Law is formed as a curb and can be broken, whereas scientific Law ceases to be Law if it is once broken.)

In the early decades of this century, it was realized that the Sun is not a special star, but only a fairly average one; and that it is not even at the centre of the Galaxy, but is almost lost in the 100,000 million other stars that make up the system. Quite a humiliating experience! The modern view is that our Galaxy is just one rather normal spiral in a local cluster of galaxies that forms just a small part of the Universe. There is no way in which we can imagine ourselves in any central position.

The propagation of views which go against the 'accepted consensus view' has always required great courage, as Galileo and Bruno found to their cost, but as we look into the history of astronomy we find that many small voices were raised in favour of the truth, even though they seemed to have little impact at the time. It is noticeable, however, that the really great statesmen of science have always been well aware of the contributions of their predecessors—even the small voices have been heard—and many have given them appropriate credit in their writings. Sometimes, and particularly at the present time, it seems almost fashionable to belittle the contributions of the big names of the past on the grounds that it was more an accident of time and place of birth that led them to make their advances. It is certainly true that such men have been able to present an overview of the work of many separate individuals and to tie the loose ends together into a comprehensive knot. Isaac Newton was one such contributor, and if anyone is tempted to disparage the greatness of his contribution or to regard him merely as a moderately outstanding man of his time—some three hundred years ago—then I would urge him to try to read and understand his 'Principia', starting at first with the English translation from the original Latin.

Newton was once asked by his fellow scientist, Robert Hooke, how he had accomplished so much. 'If I have seen further', Newton replied, 'it is by standing on the shoulders of giants.' We all too easily forget the contributions of these 'giants' and I think it is useful to go back even further than Newton had in mind to find out who they were and what they did. The following is a personal selection of those who in my opinion were some of the larger giants in an attempt to see if, perhaps in a more modern context, they might not have been Nobel Laureates.

I have chosen some of the early Greek scientists and philosophers because it was they who first began to interpret and theorize about the many observations inherited from the Babylonians and other early watchers of the skies. The progress they made was virtually from scratch, and it is difficult for us, with over two thousand years of hindsight, really to appreciate the true impact of their contributions.

Thales of Miletus (640-546 B.C) provides the best example of the use of the known cyclical behaviour of astronomical bodies in a predictive capacity. His own writings make it clear that he believed the world to be a flat disk floating in the seas, but he was aware of the cycle of lunar motion called the Saros, and he probably recognized from the lunar phases that the Moon's motion in front of the Sun is the reason for solar eclipses. He knew all about solstices and equinoxes, and he used this knowledge to predict the solar eclipse of 28 May, 585 B.C. The story is recorded by Herodotus in Book 1, Chapter 74, of 'The Persian Wars' thus:

> 'Just as the battle was growing warm, day was on a sudden changed into night. This event had been foretold by Thales of Miletus, who forewarned the Ionians of it, fixing it for the very year in which it actually took place. The Medes and Lydians, when they observed the change, ceased fighting, and were alike anxious to have terms of peace agreed upon.'

Although this is an impressive incident it is almost certain that Thales had no similar understanding of the causes of lunar eclipses since, in his view, the Sun would presumably have to be under the sea. When one remembers the crude instrumentation of those days it is remarkable that Thales was able to state that the angular diameter of the Sun is 1/720 of the whole circle.

Closely following Thales is the great geometer *Pythagoras* (572-492 B.C) known universally, but not chiefly because of his astronomical work. Born in Samos, he moved to southern Italy, where he did most of his work. He was the first to recognize that the Earth is spherical. He correctly understood the rotational scheme of things although he believed that the Earth was stationary at the centre. He defined the axis of rotation, but thought that the whole sky moved around the Earth. In the absence of any knowledge of dimensions this is a perfectly reasonable picture. Pythagoras was also one of the first to realize that the morning stars, Mercury and Venus, were the same objects as the evening stars, although he did not seem to have a clear idea as to what this implied. One of the most remarkable discoveries he made was the relationship between frequency and pitch of musical notes. This was not applied to astronomy at the time, because few figures were available, but later numerologists, notably Kepler, were to resurrect the idea in an attempt to describe planetary distances in terms of what was to become known as the music of the spheres.

Perhaps the most astonishing contribution of this period was made by *Empedocles* (484-424 B.C) of Sicily. He was very much concerned with the fundamental nature of matter, and held that everything was made from various combinations of the four basic elements earth, water, air and fire. He demonstrated the corporeal nature of air by showing that water can only enter a vessel as air escapes. He clearly understood the causes of day and night and the mechanism of eclipses, but his most fascinating speculation was that light travelled with a finite velocity. Presumably, he had watched stonemasons hammering chisels and noticed the time delay between seeing the hammer blow and hearing it. It is, however, a much larger step to muse on how the light may also be delayed, particularly since nobody had any ideas on the nature of light at that time. Evidence for the correctness of this speculation was more than 2,000 years away.

Heracleides of Pontus (388-315 B.C) stands out because of his clear perception of the true structure of the inner Solar System. Unfortunately, he was one of the lesser voices of his time, and failed to attract the attention he deserved. A contemporary of his was Aristotle (384-322 B.C), a firm believer in the geocentric theory and a leading man of his time. Aristotle extended the work of his predecessor Eudoxus (408-355 B.C) and postulated a system using combinations of perfect circles to explain the complicated planetary motions. In all, some 55 separate circles were required, and the overall result was only roughly accurate. Strange limitations were placed on the behaviour of things in that the Moon, and everything below it, was regarded as 'earthy', imperfect and subject to change. Everything above the Moon was perfect and changeless. The few glaring discrepancies like, for example, novæ that must have appeared over the years, seem not to have concerned him.

Heracleides had a clear view of at least a partly heliocentric theory. 'The stars of Mercury and Venus', he said, 'make their retrograde motions and retardations about the rays of the Sun, forming by their courses a wreath or crown about the Sun itself as centre. It is also owing to this circling that they linger at their stationary points.' This view was taken over almost as it stands by Tycho Brahe in the sixteenth century. Heracleides did not apparently extend this view to the outer planets, but the giant step had been made, and the Earth seen as a rotating spherical object that was not the centre of all rotation.

The first of the great measurers of the sky was undoubtedly *Aristarchus of Samos* (310-230 B.C). His application of mathematical reasoning to observations shows a well-developed scientific method and, although the figures he obtained seem wildly inaccurate, the principles and deductions are quite correct and give poor results only because of the inadequate equipment at his disposal. Aristarchus was fully convinced of the heliocentric structure of the Solar System, and was the first to describe it in a way that included the known outer planets. He devised a method of estimating the distance of the Sun from the Earth in terms of the Moon's distance, and went on to estimate the relative sizes of these bodies from the geometrical properties of eclipses. The method is very simple. He argued that when the Moon is seen at exactly half-phase, then the angle between the Sun's rays at the Moon and the line of sight towards the Moon must be exactly a right angle. An observer is often able to see both the Sun and the half-moon at the same time, so it is possible for him to measure the angle between the Sun and the Moon. If the Sun were at an infinite distance, then this angle would also be a right angle. If the Sun is much nearer than this, then the angle will be less than 90 degrees. Aristarchus estimated the angle to be 87 degrees, which implied a relatively near Sun. The major observational difficulty here is the determination of the exact moment of half-phase, because the lunar terminator is not clearly defined. If he had been able to measure this better then Aristarchus would have found that the actual angle is nearer 89 degrees 51 minutes—only 9 minutes of arc less than a right angle!

It is interesting to read the list of 'Hypotheses and Propositions' that Aristarchus made concerning this problem; (after 'Aristarchus of Samos' by Sir Thomas Heath.)

'Hypotheses:

(1) That the Moon receives its light from the Sun.
(2) That the Earth is in the relation of a point and centre to the sphere in which the Moon moves.
(3) That, when the Moon appears to us halved, the great circle which divides the dark and bright

portions of the Moon is in the direction of our eye.

(4) That, when the Moon appears to us halved, its distance from the Sun is then less than a quadrant by one-thirtieth of a quadrant.

(5) That the breadth of the (Earth's) shadow is (that) of two moons.

(6) That the Moon subtends one-fifteenth part of a sign of the zodiac.

'Propositions: We are now in a position to prove the following—

(1) The distance of the Sun from the Earth is greater than eighteen times, but less than twenty times, the distance of the Moon (from the Earth); this follows from the hypothesis about the halved moon.

(2) The diameter of the Sun has the same ratio (as aforesaid) to the diameter of the Moon.

(3) The diameter of the Sun has to the diameter of the Earth a ratio greater than that which 19 has to 3, but less than that which 43 has to 6; this follows from the ratio thus discovered between the distances, the hypothesis about the shadow, and the hypothesis that the Moon subtends one-fifteenth part of a sign of the zodiac.'

The most impressive measurement of this period was provided by *Eratosthenes of Cyrene* (276-196 B.C.). It is still difficult to gauge the accuracy of his work, because of a lack of evidence about the exact lengths of the units of distance that he used, but it is clear that he obtained an estimate of the radius of the earth that is very close to the modern accepted value.

Cyrene lies close to the modern city of Aswan which is almost exactly on the tropic of Cancer. Eratosthenes noticed that on a particular day of each year the sun's rays shone vertically down a well in the town. The well had been dug vertically towards the centre of the Earth using a plumb-bob, and the day was the day of the summer solstice. In Alexandria, almost 500 miles due north, he noticed that the sun's rays never came closer than 7½ degrees to vertical and he argued that this was caused by the curvature of the Earth, assuming of course that the Sun was at such a great distance that the rays striking Cyrene and Alexandria were essentially parallel. If this is the case, then the 500 mile difference in circumference subtended an angle of 7½ degrees at the Earth's centre, and it is a simple arithmetic task to calculate how many miles subtend an angle of 360 degrees. Eratosthenes arrived at an extremely good figure for the dimensions of the Earth, although it can be argued that fortuitous positive and negative errors inherent in his measuring technique probably gave him such accuracy by accident. Nevertheless, the principle is correct, and it is difficult to see how such measures can have been so widely ignored and apparently forgotten for subsequent centuries.

The final name in this brief selection must be that of *Hipparchus of Rhodes* (160-125 B.C). This giant was primarily an observer, but he made contributions which have been taken over and feature almost unchanged in modern astronomy. Hipparchus produced a star catalogue containing some 1,080 stars, and he also recorded the brightnesses of these stars on a scale where the brightest was graded as '1' and the faintest '6'. This is a crude subjective scale, but it can be related to a photometric scale where received energy is scaled using an objective measuring instrument. It is found that five of Hipparchus' grades correspond to a photometric difference of a factor of 100. When the old scale was taken over and incorporated into modern astrophysics, the grades were re-named 'magnitudes' and the energy difference for each grade was taken as the fifth root of 100, i.e. 2.512. Using the old system devised by Hipparchus we find that a first magnitude star is nearly 2½ times brighter than a second magnitude star—and so on. The scale has now been extended to include, for example, Jupiter at magnitude -2 and the faintest stars observable at magnitude 25 or 26.

This was by no means the only contribution Hipparchus made. Considerable attention was given to the motion of the Earth, and we find that he was able to measure the length of the year to within 6 minutes of its currently accepted value; he determined the inclination of the ecliptic; he measured the eccentricity of the Earth's orbit around the Sun; and he discovered the precession of the equinoxes and estimated that their backwards movement amounted to some 40 seconds of arc per year. This latter is a remarkably good figure when one remembers the modern value of just 50.3 seconds of arc per year.

One could go on and on, extending the list to include more recent work or finer detail, but I think the point has been made. The earliest scientists were no less giants than our Einsteins of modern days. The germ of an idea mentioned almost in passing may be the clue that solves a problem at a later date. Newton is credited with having formulated the theory of gravitation, but it should be remembered that Copernicus, working in the first decades of the sixteenth century, suggested 'that gravity is not an influence of the whole Earth, but is a property of its substance, which, it is thinkable, may extend to the Sun, Moon and other stars'. The trick seems to be in recognizing the truth rather than in being able to describe it accurately.

Modern science is far removed from those early days, and yet the same problems face us. Technical developments enable us to measure things with unprecedented accuracy and we can record data on the behaviour of matter over ranges of conditions that do not occur naturally on earth. And yet we still do not understand the behaviour of things. In some areas there are as many theories as there are people working in the field. We are perhaps suffering from a sort of information indigestion. There is still room for a giant or two in modern science, and I am sure that if any one of the men I have mentioned were alive today he would still stand out as one of the great contributors.

George Biddell Airy

PETER J. GARBETT

In the three-centuries history of the Royal Greenwich Observatory, since its founding in 1675, there have been twelve Astronomers Royal, each of whom have contributed in their own individual way to the advancement of astronomy and navigation. In this article, I aim to examine the life and work of one of the most prominent astronomers—George Biddell Airy.

Airy was born at Alnwick, in Northumberland, on 27 July 1801. His father, William Airy, of Luddington, in Lincolnshire, was a collector of excise; and his mother was the daughter of a well-to-do farmer from Playford, near Ipswich. He received his initial education at the Colchester Grammar School, and subsequently entered Trinity College, Cambridge; from where he graduated in 1823 as Bachelor of Arts. Airy soon became interested in astronomy, initially carrying out investigations in optics, and later in 1826 attempted to determine 'the diminution of gravity in a deep mine' in Cornwall. In that same year he was made Lucasian Professor at Cambridge, and two years later in 1828 became Plumian Professor, in charge of the new University Observatory. His control of this Observatory lasted seven years, giving him first-class grounding for the position of seventh Astronomer Royal.

On 11 August 1835, at the age of thirty-four, Airy was appointed Astronomer Royal, precisely 160 years from the day when Flamsteed laid the foundation stone of the Royal Greenwich Observatory.

Unfortunately, his predecessor, John Pond, had left the Observatory in a sorry state of affairs. This was due either to his failing health, or a genuine lack of interest in the running of the Observatory. Certainly Pond had made the grave mistake of employing 'drudges' as he called them, for assistants. These were men who regarded the art of observation a 'mechanical act', and calculation a 'dull process', thereby eroding the prestige of the Royal Observatory. Airy, however, in a letter to the Admiralty, recognised the importance that the First Assistant should be 'a man of respectable rank in society. This alone can give hope of security against the danger of being corrupted with money by makers of chronometers, and of losing authority over the subordinate assistants by having recourse to them for assistance in disgraceful difficulties: both which things, according to common report, have occurred at the Royal Observatory. It was partly for this reason and partly for the general object of raising the tone of science in the Royal Observatory by introducing a person of high mathematical attainments that I have strongly recommended a Cambridge man. With respect to habits of patient industry, they may sometimes be found among Cambridge men in a very eminent degree.'

The gentleman that Airy suggested was Robert Main, and since Airy, himself, was a Cambridge man, a tradition of Cambridge scholars at the Observatory was continued.

Airy's job was not to be easy. In 1835, the First Lord and the Secretary of the Admiralty stated quite plainly to Airy 'that the Observatory had fallen into such a state of disrepute that the whole establishment should be cleared out'. At Cambridge, he had received a salary of £600 p.a., similar to the Astronomer Royal's salary at the time. A move from Cambridge to Greenwich would hardly have been worth while without a suitable incentive, as Airy was prepared to point out. After a formal application to the Admiralty, and with some financial jugglings, he was given an additional £200 p.a.

After his appointment, he immediately set to work to put the Observatory back on its feet with remarkable efficiency. His obsession with order sometimes appears to have been taken to extremes, as one of his assistants later remarked: Airy's 'love of method and order was often carried to an absurd extreme, and much of the time of one of the greatest intellects of the century was often devoted to doing what a boy of fifteen shillings a week could have done as well, or better. The story has often been told, and it is exactly typical of him, that on one occasion he devoted an entire afternoon to himself labelling a number of wooden cases "empty", it so happening that the routine of the establishment kept everyone else engaged at the time. His friend Dr Morgan jocularly said that if Airy wiped his pen on a piece of blotting-paper he could duly endorse the blotting-paper with the date and particulars of its use, and file it away amongst his papers'.

Airy had great ability in the field of engineering, and this was reflected in a whole variety of gadgets installed at the Observatory. The first professor of engineering at Cambridge described Airy as 'one of the most remarkable men, indeed I think I may say the most remarkable man, whom I ever met'. He went on to describe the multitudinous inventions Airy had installed at the Observatory, which included, 'arrangements for holding papers, for making clocks go simultaneously, for regulating pendulums, for arranging garden beds, for keeping planks from twisting, for every conceivable thing from the greatest to the smallest'. It is certain that his natural abilities in engineering helped him to equip the Observatory with a variety of new instruments, as will all be discussed in detail below. One major obstacle, though, in the past had been the administrative bodies, a problem which Airy managed to surmount.

The Royal Observatory had been in the charge of the Admiralty since 1818, and it appears that Airy got off on the right footing with this major administrative body. If he required Government assistance in any project, he would state clearly and briefly why he wanted it, and what benefits he expected from it. He would then place himself personally responsible for the direction of the project, making everything perfectly straightforward for the statesmen, who rarely had any objections. Consequently, there was no delay or inquiry, since the project was under way before the objectors had chance to grumble. This method of proceeding enabled Airy to obtain for the Observatory a variety of new and valuable instruments. In 1843, for example, Airy ordered a large altazimuth instrument; best described as a very large theodolite used to find a body's altitude and azimuth, which, even though an accident occurred at one of the construction plants, was first used on 16 May 1847.

In that same year of 1847, Airy began campaigning for a large transit circle (instrument which was a combination of a transit instrument and a mural circle, in which the transit time, and altitude or polar distance of a body, could be determined simultaneously). Airy arranged for this instrument to have an object-glass of 8-in (20-cm) aperture, and a focal length of 11 ft 6in (3.5 metres), and it made its first observation on 4 January 1851.

One consequence of Airy's transit circle was that it determined the Greenwich Meridian, in place of Troughton's transit instrument; representing a shift of 5.8 metres to the east, corresponding to 0.02 seconds of time.

Airy's transit circle was used to investigate the motions of the Sun, Moon and planets, in addition to important measurements of the proper motions of stars. Its uses also extended to the observation of asteroids, which once led Airy to state in desperation, 'I do not like small planets.' Since its first observation, early in 1851, it made a remarkable 750,000 observations over the years of its active use.

The Royal Observatory has derived fame for its time signals, and Airy was responsible for developing further what had began in earnest during Pond's time. Since 1833, a relatively simple time-signalling device had been in operation at the Observatory. This was Pond's time-ball which, mounted on the eastern turret of the Royal Observatory, had been used as a time-signalling device for ships in the surrounding docks on the Thames. The basic principle was that at one-o'clock p.m. solar time the ball would be dropped, giving an opportunity for vessels to regulate their chronometers. In the 1840s, early in Airy's time, Greenwich time began to be used as 'railway time' throughout Great Britain; and in 1852, Airy installed at the Observatory the Shepherd 'Motor Clock', controlling by telegraph various time devices over the great railway network.

As Astronomer Royal, Airy is also well remembered for the construction of his 12¾-in (32-cm) refracting telescope. The objective was manufactured by Merz of Munich, and the instrument mounted on a very large and strong arrangement. This same mounting was later used by Christie, eighth Astronomer Royal, to mount his great 28-in (71-cm) refractor in 1894. Today this instrument may be found at the Old Royal Observatory, Greenwich, on the original Airy mounting in the fine 'onion-dome'. The Airy refractor was housed in the so-called 'Great Equatorial Building', built in 1857, and by 1859 was fully operational. It is interesting to note that Airy's original Equatorial Building had a 'drum-dome', but when the 12¾-in (32-cm) refractor was replaced by the larger 28-in (71-cm) instrument, Christie housed it in a more spacious 'onion-dome'.

Airy, as seventh Astronomer Royal, was responsible for establishing two major new departments. In the late 1830s, he built a magnetic observatory at Greenwich, and established the Magnetical and Meteorological Department. Considerably later, in 1873, he founded the famous Solar Department, a reflection of his own personal interest in the Sun, and the growing interest in connections between solar activity and terrestrial magnetism.

So Airy contributed many material things to the Royal Observatory during his period of office, but we must not forget that his great administrative and engineering abilities were slightly overshadowed by a certain oft quoted and unfortunate historical incident.

Relatively early in Airy's career, it had been noticed that since the discovery of Uranus in 1781, the orbit of this planet was somewhat different from its predicted path. It was apparent that some outside body was responsible for these perturbations, and one answer seemed to lie with a hitherto undiscovered planet beyond the orbit of Uranus. However, the mathematical difficulties involved in interpreting these observations, and computing the position of this new planet, were manifold.

John Couch Adams, a young scholar fresh from Cambridge, had the mathematical power to make the necessary calculations, and by September 1845 had reached a full solution. On the advice of Challis, Professor of Astronomy at Cambridge, Adams attempted to communicate the results of his investigations to Airy, *en route* for a vacation in Cornwall. On arrival at Greenwich he found that Airy was in France, so he left a note of his results, and went on vacation. Returning from Cornwall, on his way back to Cambridge, Adams called for a second time at the Royal Observatory, only to find that Airy was out, but would return later. He came back in half an hour, to be told that Airy could not be disturbed since he was dining. A disappointed Adams, therefore, left for Cambridge, not having seen Airy.

Airy was a good mathematician, but on examining the work of Adams he could not convince himself that the young man had succeeded in solving the inverse perturbation problem. Instead, he felt that Adams had merely guessed at hypothetical orbits for the new planet and tested their viability. It was probably for this reason that Airy did not do anything constructive for a long period of time concerning Adams' calculations.

Meanwhile, across the Channel in France, another distinguished mathematician, U. J. J. Le Verrier, was working on the same problem, unaware of the efforts of Adams in England. Le Verrier came to very similar conclusions as our young mathematician; however, in his case, after his predictions had been sent to the Berlin Observatory in 1846, more immediate action was taken by two astronomers, Johann Galle and Heinrich d'Arrest, who soon discovered the planet. It must, however, be pointed out that the French had a suitable star-chart available, whereas the English had to construct their own when Airy eventually gave instructions for the search (carried out at Cambridge by Challis). When the discovery became common news, a great storm broke in the astronomical world.

It was very apparent that had Airy begun searching for the new planet when he first heard of its probable position from Adams a year earlier, the discovery of Neptune, as it was eventually called, would have gone to an Englishman. The battle which ensued was unfortunate to say the least, and gave

Airy an unpopular name. Today, we generally regard the discovery of Neptune as due both to the calculations of Adams and Le Verrier, but we cannot forget the unfortunate role Airy played in its discovery.

Eventually, the Neptune incident became a thing of the past, although Airy could never forget his own mistake. He continued to add instruments to the Royal Greenwich Observatory until the end of his career, and by 1870 we begin to sense that a change of emphasis was in the air. In this year, Airy wrote: 'Still the question has not infrequently presented itself to me, whether the duties to which I allude have not, by force of circumstances, become too exclusive; whether the cause of Science might not gain if, as in the Imperial Observatory in Paris for instance, the higher branches of mathematical physics should take their place by the side of Observatory routine.'

The Royal Observatory was originally founded, 'in order to the finding out of the longitude of places for perfecting navigation and astronomy . . . ' Airy, rather reluctantly recognized the need for a major change in the research programme of the Observatory, a change which was to come after Airy's time, and boil up into a major debate in which the existence of the Observatory was questioned.

Airy was given the distinction of a Knight of Commandership of the Bath in 1872, after having declined it on previous occasions. He resigned office on August 15, 1881, a year after G.M.T. became legal time in Great Britain. Airy had devoted a remarkable forty-six years of his life to the Royal Observatory, and was aged eighty at his resignation. He continued to live at the White House, just outside Greenwich Park, until his death on 2 January 1892, and survived to see his great transit circle mark the Prime Meridian of the world. The 27-country assembly in Washington who decided upon this in 1884, could not have created a more fitting monument to a truly great astronomer.

CHIRON: A new type of object in the Solar System

CHARLES T. KOWAL

In the past few years, astronomy has been enriched by the discoveries of quasars, pulsars, X-ray sources, and black holes. In 1977, we found that our own neighbourhood, the Solar System, still holds some surprises too. In March, rings were discovered around Uranus, and in November, I found a still-unclassified object between the orbits of Uranus and Saturn. This object appears to be a new type of body—too remote to be an asteroid, too large to be a comet, and too small to be a planet. I have suggested the name 'Chiron' for this object.

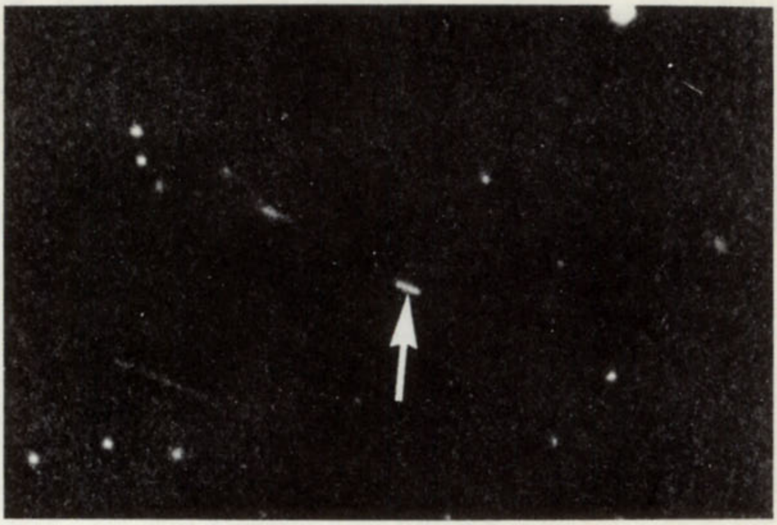
I discovered Chiron during a systematic survey of the Solar System. The original intent of this survey was to find comets at large distances from the Sun, and thus to improve our knowledge of the distribution of comets. During 1977, I discovered one comet and one unusual Apollo-type asteroid. I also recovered the lost asteroid, *Adonis*, and Comet Taylor, which had not been seen since it broke into two fragments in 1916. I then discovered Chiron on 1 November.

My Solar System survey uses the 48-inch Schmidt telescope at Mount Palomar. This telescope is essentially a fast (f2.5), relatively wide-angle camera. It photographs an area of the sky 6.6 degrees square. The photographs are taken on special 14-inch glass photographic plates. For about the past 8 years, new types of photographic emulsions, new developers, and new sensitization techniques have made it possible for the 48-inch Schmidt telescope to photograph objects as faint as the 21st magnitude. The plates I use are called Kodak 'IIIa-J' plates. Before exposing, the plates are *baked* for seven hours in an oven filled with nitrogen gas. This procedure increases the speed of the emulsion by about a factor of eight. The plates are exposed in the telescope for 75 minutes, and developed in a high-contrast developer called 'MWP-2'.

Each month, I photograph an area near the 'opposition point' of the ecliptic. The opposition point is that part of the sky which is exactly 180 degrees from the Sun. At opposition, the objects in the Solar System are moving at their maximum retrograde velocities. Their apparent speed is a function of their distance. Asteroids very close to the Earth—the 'Apollo' asteroids—can move several *degrees* per day, while the planet Pluto moves less than two *minutes* of arc per day. When an object is sighted on a photograph, it is therefore possible to quickly obtain an estimate of its distance. More importantly, the differences in motion make it possible to distinguish between the ordinary asteroids and the more unusual objects. Since there are approximately 200 asteroids on every photograph, it is extremely important to be able to reject the 'uninteresting' ones! This can only be done within about 15 degrees of the opposition point. Beyond 15 degrees, the asteroids move at a slower apparent speed, and become indistinguishable from more-distant objects.

Photographs of the appropriate areas are taken on each of two successive nights. The photos are immediately examined with a magnifying glass, in order to find fast-moving objects or bright comets. Afterwards, the plates are examined very carefully in a 'blink microscope'. This is a device which shows a segment of, first one plate, and then the other, in rapid alternation. While the stars appear stationary, moving objects appear to jump from side to side in the field of view. This is a very simple, but powerful, technique.

In October, 1977, I was only able to obtain one pair of plates for my survey. These were taken on the nights of 18 and 19 October. A quick inspection of these plates revealed no comets or Apollo asteroids. A detailed examination of the plates had to wait until I returned to my office in Pasadena. Finally, on 1 November, after several hours of 'blinking', I spotted a very short trail on each of the plates. The object which made these trailed images was moving about 3 minutes of arc per day. I



'CHIRON', 19 October, 1977. 75 minute exposure with Palomar 48-inch Schmidt telescope.

estimated its magnitude as roughly 18. Since its motion was only slightly faster than the motion of Uranus at opposition, it seemed probable that the object was just inside the orbit of Uranus. The image appeared very sharp and 'un-cometlike'. Furthermore, its brightness implied a diameter of several hundred miles—about one hundred times larger than typical comet nuclei. On the other hand, it is about ten times smaller than the smallest planet, and, though comparable in size to the largest asteroids, it was 1.4 thousand million miles from the asteroid belt!

The first thing to be done, after making a discovery of a moving object, is to notify other astronomers, and to ask them to obtain observations of the object. I therefore called Dr Brian G. Marsden, of the Central Bureau for Astronomical Telegrams, and gave him the precise positions of my object. Dr Marsden then telegraphed the news to astronomers throughout the world. The first to respond was Dr Tom Gehrels, of the University of Arizona. He had photographed that part of the sky on 11 October. Using the positions given to him by

Marsden, he quickly found the object near a corner of his plates. Then, on 4 November, Drs Richard Green, Douglas Richstone, and Mr Tod Boroson photographed the object. These three sets of observations, from 11 October through 4 November allowed Dr Marsden, and Dr James G. Williams, of Cal Tech's Jet Propulsion Laboratory, to compute a preliminary orbit. These calculations confirmed that the object was, indeed, between the orbits of Saturn and Uranus, although the shape of the orbit was still indeterminate. At this point, the object received the temporary designation, '1977 UB'.

More observations were accumulated in November, until a fairly accurate orbit could be computed. Using this orbit, Marsden computed the positions of the object for several years in the past. I was then able to find the object on plates I had taken in 1969. A further refinement of the orbit enabled me to find it on plates taken in 1952. Then, Dr William Liller and Lola Chaisson, of the Harvard-Smithsonian Center for Astrophysics, looked through the extensive plate collection at Harvard Observatory, and were able to trace the object all the way back to 1895! The object had been photographed for over 80 years, or one and a half revolutions around the Sun, before it was finally discovered in 1977! The orbit is now known very accurately, and shows that the object travels from 8.5 to 18.9 astronomical units from the Sun. This takes it from inside the orbit of Saturn, to just about the orbit of Uranus. The semi-major axis of the orbit is 13.7 A.U., and the eccentricity is 0.38. The period of revolution is currently 50.7 years, but this period is somewhat variable, because of the gravitational pull of Saturn, Uranus, and Jupiter. The average period over many revolutions is about 49 years. The orbit is inclined 6.9 degrees to the ecliptic. The next perihelion will occur in 1996. Previous perihelia occurred in 1945 and 1895. At perihelion, the object brightens to 15th magnitude. This is what made it possible to detect the object on the very old plates. The diameter of the object may be anywhere from 100 to 400 miles.

It is not yet known whether the orbit is completely stable. In spite of an occasional close approach to Saturn, there is no conclusive evidence that the object will some day be perturbed into a different orbit, or that it was formed in some other part of the Solar System and captured into its present orbit.

Since it was, and still is, impossible to classify this object, I felt that it should at least be given a proper name. Bearing in mind that similar objects might be found in the future, I looked for a well-defined *group* of mythological beings whose names had not yet been used. Upon looking through a list of asteroid names, I found that there were no *Centaurs* among the 2,000 named asteroids. The best-known Centaur is *Chiron.* Chiron happens to be a son of Saturn, and a grandson of Uranus, which ties-in well with this object's orbit. If other such objects are found in the outer Solar System in the future, they could be named after other Centaurs, and, as a group, could be called the 'Centaurian planetoids', the 'Centaurian objects', or some such designation. The International Astronomical Union will have to decide on the proper terminology. They will also have to make a formal definition of the terms 'planet' and 'asteroid'. How big must an object be to be called 'a planet'?

The asteroids are technically called 'minor planets'. This term may be broad enough to include Chiron, but I feel that this object should be distinguished from the asteroids in some way. Perhaps the term 'planetoid' could be used for minor planets in the outer Solar System.

The composition of Chiron is still unknown. However, as Chiron gradually comes closer to the Sun, it will become bright enough to be studied in considerable detail. Observations in visible and infra-red light should enable us to measure the size of Chiron and to determine the composition of its surface. Until these observations are made, we can only speculate about the nature and origin of this strange object.

Current speculation about Chiron can be divided into the following four theories:

1. Chiron is an enormous *comet,* which was captured into its present orbit. It does not look like a comet because it is too far from the Sun for its ices to be evaporated. The main objection to this theory, at present, is that we have never before

seen such a huge comet. If the orbit turns out to be stable, this would also argue against the 'capture' hypothesis.

2. Chiron is an *asteroid* which was 'somehow' transported into its present orbit by perturbations from Jupiter and Saturn. Unless we some day find a large number of asteroids between the orbits of Jupiter and Saturn, this theory seems highly improbable.

3. Chiron is a *planetesimal*—a surviving remnant of the building blocks which coalesced to form the outer planets. This might be possible if Chiron's orbit is stable on a time scale of 4 thousand million years. If this theory is correct, Chiron could give us much information about the formation of the outer parts of the Solar System.

4. Chiron is an escaped satellite of Saturn. Chiron actually passed within 10 million miles of Saturn in 1664 B.C.—roughly the same distance as Saturn's outermost satellite, Phœbe. This may, however, tell us more about Phœbe's origin than about Chiron's.

Detailed studies of the composition of Chiron, and of the stability of its orbit, may allow us to decide between these theories in the next few years. Until then, Chiron remains a mystery.

Lunar Transients; Their History and our Theories

MICHAEL BODE

When we view the Moon today we can feel fairly certain that its pockmarked face appears exactly the same to us as it did to the very earliest of men. Most of the major features were almost certainly formed very early on in the creation of the Solar System—long before any life existed on the Earth. To further this image of total inertness the Moon has also contrived to confront us with roughly the same face each day. On a few rather rare occasions, however, dedicated observers have been privileged to witness events which indicate that the Moon is not geologically dead, just soundly asleep.

Obviously in pre-telescopic days any small disturbances on the surface of our nearest neighbour were likely to go totally unnoticed. Surprisingly though, we do possess a few reports dating from the days before Galileo. One of the earliest reports I have encountered dates from A.D. 1096 (1) and speaks of a bright light being seen on the Moon during an eclipse. This, like other early reports, is extremely vague. It seems to have the observation of a bright, or 'star-like' point of light against a dark lunar background in common with many other early reports however. One very lucid account is given by an unknown Englishman in the spring of 1587 (2):

> 'A Sterre is sene in the bodie of the Mone upon the (5th?) of Marche, whereat many men merueiled, and not without cause, for it stode directly betwene the pointes of her hornes the Mone being chaunged not passing 5 or 6 daies before.'

It is quite clear that something rather unusual had happened, but as in the case of nearly all the reports there is no indication that a similar thing occurred when next the Moon was at the same phase, or indeed that any of the permanent features of the surface had been at all altered.

With the advent of the telescope, the number of reports of strange, short-lived changes increased—as did their variety. Of course people were not only better equipped to observe faint events, but there were many more observers making detailed observations in a systematic way than ever there had been before. These observers noted the same sort of events that many people claim to witness today. These include obscurations of surface detail; bright flashes or 'sparklings'; steady points of light or diffuse patches and anomalous changes in the brightness of certain well-known features. In some of the more interesting cases colours were assigned to the events, these being as today predominantly reds and blues. It was not until the late 18th century however that any great attention was paid to these reports. What it took was a series of startling observations by a well-respected astronomer of the day—something that was to be repeated in our own times as we shall see.

The reports that shook the astronomical world came from no less a man than William Herschel, then working in Windsor. Throughout the 1780's, he reported seeing unusual points of light at various locations on the lunar surface. However, it was the observations of 19 and 20 April 1787 that really had the greatest impact on his fellow astronomers (3).

On the two nights in question, this incredibly able and experienced observer saw what he felt sure were three active 'volcanoes' pouring forth molten lava on to the lunar surface. The picture he gives us is of these three points, then on the dark side, illuminating the surrounding peaks with a nebulous light 'like glowing coals'. One can easily understand from his account why he ascribed the phenomena to a volcanic event of great violence. He himself estimated the brightest volcano to be a minimum of 5 km in diameter.

Over the next few years, observers such as Schröter and Bode added many credible observations to the growing list. Indeed, at first glance, this time would seem to have been an exceedingly active one on the Moon. The truth is probably that it was the activity and sheer dedication of the observers on the Earth, and perhaps even some over-zealousness, that led to the large number of interesting reports we have from that period. In contrast, if we look at the years from 1800 to 1820 we find very few reports, due largely to the destruction of observatories and library records during the Napoleonic wars. It is this sort of interference and selectivity in results that makes analysis of past records so hazardous.

During the 19th century, a steady stream of reports came in, growing in number as the century drew to a close. However, in 1866, a controversy erupted with the unexpectedness of Herschel's 'volcanoes'. This concerned what we now see as a light 'smudge' in the west of Mare Serenitatis. I refer, of course, to the 'crater' Linné, discovered by Riccioli during the 17th century. Three reputable observers, Lohrmann, Mädler and Schmidt all noted it as a crater. Schmidt drew it as a crater in eight of eleven drawings between 1840 and 1843. In 1866, this same astronomer announced to the world that Linné only appeared as a mound, as it does now (4). The crater had apparently disappeared, except for a tiny craterlet observed atop the mound in 1867.

The controversy over Linné still carries on in some quarters today, but with a lack of photographic evidence the arguments are liable to be based more on personal opinions. If, nevertheless, we assume that Linné has undergone some sudden metamorphosis, then it is the only time in history that a permanent change has been recorded on the Moon, other than by man-made interference.

The 20th century saw the dawning of an age when good astronomical telescopes came within the reach of many ordinary men and women who had the time and patience to observe the Moon for long periods for the sheer joy of doing it. It also saw the mushrooming of reports which must go hand in hand with the sudden increase in the number of observers particularly after the Second World War.

A great deal of observational work was done in the late 1940s and 1950s by James Bartlett in Baltimore, U.S.A. (5). He reported a large number of events (107 in his 1967 catalogue) many of them coloured and the majority in and around the brightest large-scale feature on the Moon, the crater Aristarchus. The observations he made were, however, with relatively small aperture reflectors and in some instances open to question (though some reports were confirmed by other, independent observers). Getting the professional astronomers of the day with large instruments at their disposal to spend long periods of costly observational time looking for rare and, to some, imaginary effects was almost impossible. It needed a stroke of amazing luck to change that situation. On the night of 2-3 November 1958, that is exactly what the astronomical world got.

The well-respected Russian astronomer, Nikolai Kozyrev, was conducting spectral observations of the planet Mars with the 50-in reflector at the Crimean Astrophysical Observatory. During the observations, it was decided to obtain photometrically standardized spectrograms of lunar details, particularly from the crater Alphonsus. It was in that crater in October 1956 that a set of photographs taken by Dr Dinsmore Alter with the 60-in telescope at Mt Wilson through a series of different filters seemed to show some 'washing out' of details on the crater floor, particularly for plates taken in the blue/violet region (6). Kozyrev's observations between 1 a.m. and 3.40 a.m. on 3 November 1958 provided more conclusive evidence of something strange going on inside Alphonsus.

At 1 a.m., whilst the slit of Kozyrev's spectrograph was across the central peak of Alphonsus, the latter 'became strongly washed out and of an unusual reddish hue' (7). At 3 a.m., a further spectrogram was taken and the peak seemed unusually bright. This brightness gradually subsided and a further exposure was taken between 3.30 a.m. and 3.40 a.m. When the spectrograms were developed and studied, they seemed to indicate that some kind of slow leakage of gas (which had in some way become excited) had occurred from the small craterlet at the top of the central peak of Alphonsus. Kozyrev thought he could even identify the so-called 'Swan bands' of molecular carbon commonly found in cometary spectra. Other astronomers were not as convinced about this more specific interpretation. However, many were certain that concrete proof now existed supporting the view that the Moon periodically experiences slow leakages of gas from its substrata to the surface.

In the early 1960's reports from professional astronomers such as Greenacre and Barr in Arizona (8) and Kopal at the Pic du Midi (9) added more fuel to the fires of controversy over the causes of these events. Coming in too were reports from organized groups of observers within the BAA lunar section and also those in the U.S.A. associated with 'Operation Moon Blink' (10). This was specifically established to detect 'Transient Lunar Phenomena' (TLP), as they were now called, using a standardized, simple piece of apparatus known as a 'Moon Blink device' (basically a device with movable filters to detect temporary colour phenomena).

Many theories about the origins of TLP emerged from the evidence amassed. These included luminescence (the storage of energy at the surface and its subsequent release); incandescence (the emission of light by a hot body such as lava) and electrical discharges arising in a cloud of gas-borne dust (11).

It was realized by Barbara Middlehurst and Patrick Moore that before any really detailed study of TLP could be carried out past reports would have to be collected and critically assessed. They therefore compiled their well-known catalogue of events which was published by N.A.S.A. in 1968 (12). Since then an extension has been published by Moore (13) and an independent catalogue compiled by Cameron in the United States (14).

Once a catalogue had been compiled the reports could be analyzed more easily and correlations were looked for. The most unquestionable correlation that emerged was that of position of events with the edges of the Maria. When the seismometers were left on the Moon by the Apollo astronauts the moonquakes that could be assigned a position of origin largely occurred at the Mare edges. Thus, the suggestion that TLP were in some way linked to seismic activity gained greater weight.

Another great step forward in our understanding of processes likely to cause TLP come with the analysis of lunar samples in the Earth's scientific establishments. The results from these analyses showed conclusively that no form of luminescence could produce effects bright enough to be visible against the sunlit face of the Moon and in any case it could not explain TLP occurring much beyond the terminator on the dark side. By now incandescence was also discarded as a cause, for two main reasons: first, outpourings of molten lava would cause permanent, not transient, changes; and secondly, although the effect might fade rapidly in the visible waveband, it would remain detectable in the infra-red for a considerable time. No such long-term effects have been noted. What was now required was a comprehensive theory to tie in all the known facts.

It had been accepted for some time before the Apollo missions that the lunar surface was covered for the most part by a very fine dust. This dust consists of particles which are typically not more than a few millionths of a metre across. The suggestion was that an outpouring of gas would levitate the fine dust layer, effectively smoothing it out, increasing its reflectivity and therefore its brightness. Some of the levitated grains would become charged in collisions with other grains. The magnitude, and sign of the charge would roughly depend on the radius of the grain. With escaping gas providing the upward force some grains might escape far enough from the surface to effectively form a 'cloud' with smaller grains at the top. This difference of grain size across the cloud might well cause a potential difference to be established across the cloud leading to lightning-type discharges such as those seen on Earth in the plumes of dust rising from volcanoes (15). These effects would only last roughly for the time the gas was escaping and after this stopped, under lunar conditions, things might return to their former state. (This whole theory and discussions of others can be found in a recent publication by Drs Allan Mills and John Geake, who have carried out a great deal of laboratory work into possible processes (16).)

The phenomena involved in the latest theories are extremely complex as anyone who has studied the behaviour of fine dusts at low pressures and their light scattering, absorption and re-emission properties will appreciate. There are also numerous difficulties to be overcome in any study of possible mechanisms. For example, it has been demonstrated that 'fluidization' of beds of fine dust by passing gas through them can enhance the reflectivity of the surface, but the bed suffers a permanent change, not a transient one at atmospheric pressure. The duplication of these experiments in ultra high vacuum conditions may well produce transient effects but the work is not yet complete.

Although they have lost some of their mystery, lunar transients are still to some extent enigmatic but the evidence is there that they are more than just instrumental, atmospheric or psychological effects, and they provide the dedicated amateur with the opportunity of sharing in the search for the final answer to this most intriguing mystery.

References

1. Newton, Robert R. *Mediaeval Chronicles and Rotation of the Earth,* p. 690.
2. Harrison, J. C., 1876. *Description of England,* Ed. Furnivall.
3. Herschel, W., 1787. *Phil. Trans. R. Soc.,* London, **77,** p. 229.
4. Alter, D., 1963. *Pictorial Guide to the Moon,* Chap. 16, p. 145.
5. Bartlett, James C., 1967. *Strol. Astr.,* **20,** No. 1-2, pp. 24-28.
6. Alter, D., 1957, *P.A.S.P.,* April, p. 158.
7. Kozyrev, N. A., 1959. *Sky and Telescope,* Feb., p. 184.
8. Greenacre, J. C., 1963. *Sky and Telescope,* **26,** p. 316.
9. Kopal, Z., and Rackham, T. W., 1964. *Sky and Telescope,* **27,** p. 140.
10. Cameron, W. S., and Gilheany, J. J., 1967. *Icarus,* **7,** pp. 29-41.
11. Mills, A. A., 1970. *Nature,* **225,** pp. 929-930.
12. Middlehurst, B. M., Burley, J. M., Moore, P., and Welther, B. L., 1968. NASA Technical Report, (NASA TR R-277).
13. Moore, P., 1971. *J. Br. Astr. Ass.,* **81,** pp. 365-390.
14. Cameron, W. S., 1972. *Icarus,* **16,** pp. 339-387.
15. Pliny, Second Letter to Tacitus (*c.* 106).
16. Geake, J. E., and Mills, A. A., 1977. *P.E.P.I.,* **14,** pp. 299-320.

The Atmospheres of Uranus and Neptune

GARRY E. HUNT

1. Introduction—Remote Sensing of Planetary Atmospheres

The past few years have seen a detailed exploration of the terrestrial planets, Venus, Mars and Mercury, and the major planet, Jupiter, by space probes. Mars has a dust-covered, cratered surface with numerous volcanoes; its atmosphere is thin, composed almost entirely of carbon dioxide but is capable of a violent meteorology which regularly generates huge dust storms near to the time of perihelion. Venus is shrouded by an extensive yellowish veil of clouds; its atmosphere, too, is almost entirely carbon dioxide, but it has a surface pressure a hundred times greater than that of the Earth where the ambient temperature is extremely hot at about 737 degrees K, and dramatic motions at stratospheric levels. Mercury, though like the Earth on the inside, has an exterior that is heavily cratered like the Moon. Any theory of the development of the Solar System must explain the extreme differences between these terrestrial planets, on the one hand, and the major planets beyond the asteroid belt, namely Jupiter, Saturn, Uranus and Neptune, on the other hand. These are huge, rapidly rotating, low-density objects with optically thick, reducing atmospheres (Table 1). They contain more than 99 per cent of the planetary mass in the Solar System. The low density suggests that, like the stars, they are entirely composed of light elements, hydrogen, helium, carbon and nitrogen; whereas, silicates, iron and nickel chiefly constitute the cores of the inner planets. Since hydrogen and helium are thought to be the principal constituents of the solar nebula, understanding the origin and evolution of these giant planets may hold important clues to the formation of the Solar System.

TABLE 1. *Physical Data of the Planets*

	Earth	*Jupiter*	*Saturn*	*Uranus*	*Neptune*	*Pluto*
Mean distance from Sun (A.U.)	1	5.2	9.5	19.1	30	39
Period of revolution	365.26 days	11.86 yrs	29.46 yrs	84.01 yrs	164.8 yrs	247.7 yrs
Rotational period	$23^h56^m4^s$	$9^h50^m30^s$	10^h14^m	24 ± 3^h (Retrograde)	$15-18^{h}$*	6^d9^h
Mass(Earth = 1)	(5.97×10^{24}kg)	317.89	95.18	14.6	17.2	0.11
Equatorial radius (km)	6378	71400	60000	25900	24750	3000
Mean density (g cm^{-3})	5.5	1.3	0.7	1.2	1.7	?
Volume (Earth = 1)	1	1316	755	67	57	0.1?
Oblateness	0.003	0.06	0.1	0.01–0.03	0.02	?
Satellites	1	13	10	5	2	0

*See Table 2 for more detailed information.

Recent investigations have shown that the major planets may form two separate families of planets. Jupiter and Saturn appear to have an atmospheric composition similar to that of the Sun. Uranus and Neptune seem to be different, with less than solar proportions of the light elements and larger proportions of methane than found on their neighbouring giant planets. This important information provides a major constraint on theories of the origin of the Solar System, and emphasizes the need to improve our understanding of the other planets to the level where a detailed comparison of the differences and similarities of all the planets may be made.

In this article we review the recent observational studies of the atmospheres of Uranus and Neptune. The information on these planets has to be inferred from measurements of the electromagnetic radiation that we receive from them by remote sounding, from the Earth or from artificial satellites. Direct sounding by entry probes will no doubt make a significant contribution in due course. Some of this radiation is sunlight that the planets and their atmospheres reflect back to space, and the rest is the infra-red that the planets radiate thermally.

The intensity of the thermal radiation at a given wavelength is usually specified in terms of an effective brightness temperature. At wavelengths for which the planetary atmosphere is optically thin, the effective temperature will be the actual temperature of the surface material or of the atmosphere in the neighbourhood of the tops of any dense clouds. The emission spectrum may, however, also show structure, due to the characteristic spectra of the molecular species in the atmosphere, and the relative intensities of these spectral features will be sensitive to the structure of the atmosphere. For example, lines can appear in emission if the atmosphere's temperature increases with altitude, or in absorption if the temperature decreases with altitude. Generally, at any wavelength in the thermal infrared where an atmospheric constituent possesses strong absorption, the radiation intensity leaving the top of the atmosphere is a function of the distribution through that atmosphere of the emitting gas, as well as of the distribution of temperature. An isolated absorption band can, however, be usefully employed to derive the temperature structure if the emitting constituent is substantially uniformly mixed in the atmosphere and local thermodynamic equilibrium is maintained throughout.

The solar-reflected radiation runs from the shorter infrared wavelengths through to a peak in the visible range and extends into the ultraviolet portion of the spectrum. The intensity will depend upon the albedo of the surface or cloud layer, and spectra from the constituent atmospheric molecules may be superimposed in absorption. Imaging techniques may be used to show structural features, such as clouds, the movements of which reveal winds and other dynamical aspects of the atmospheres. The light from a bright star may also be used to probe planetary atmospheres, by observation of the star in occultation by the planet.

To build up an understanding of a planetary atmosphere thus requires careful observations of several kinds, through the electromagnetic spectrum, followed by detailed analysis using realistic models. It is this approach that has been followed to obtain our current understanding of the atmospheres of Uranus and Neptune which we review in the following sections.

2. Basic Properties

2.1. Composition and Structure

Uranus and Neptune are smaller and colder than their giant companions (Table 1). Using the present estimates of their radii we may conclude that objects the size of Uranus and Neptune with solar composition would have maximum densities of ~200 and 1,800 kg.m^{-3}. Their presently derived mean densities are about ~1,200 and 1,700 kg.m^{-3} respectively (Table 1). It is clear that these planets must have less than solar proportions of the light-abundant elements hydrogen and helium and therefore are in contrast to Jupiter and Saturn which apparently are close to solar composition.

This distinction between the planets may be illustrated by a study of a mass radius diagram as we show in Figure 1. Here we have plotted the mean density (M/R_0^3) of an individual planet against the logarithm of their masses normalized to the mass of the Earth. As the mass of the planet increases, we will determine a corresponding increase in the central pressure and mean density of the object. If all the planets had the same composition, then we should observe in Figure 1 a monotonic increase of density with mass. It is apparent from the diagram that this is not the case, implying differing compositions and molecular weights for the planets. Since planets with higher mean molecular weights must have either a higher mean density or a lower mass, this suggests that the planets in the upper left-hand portion of Figure 1 (the terrestrial planets) have the highest molecular weights, while those in the lower right region (the major planets), have the lowest values. This clearly shows that Uranus and Neptune are enriched in heavier elements, but not as much as the terrestrial planets, and form a different family of objects from Jupiter and Saturn, in the outer Solar System.

Although the great distance from the Earth to Uranus and Neptune has made them difficult objects to study at any

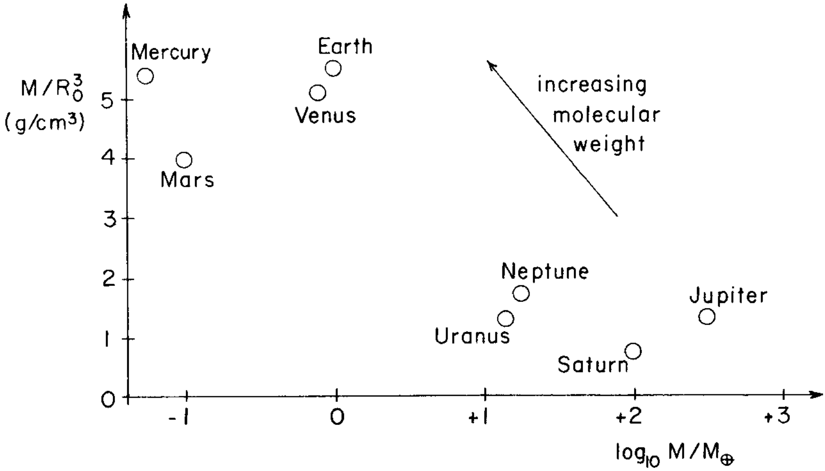


Figure 1. Mass-radius diagram for the planets (after Stone, *Icarus,* **24,** 292-298 (1975))

wavelength, the available spectroscopic information confirms this broad composition difference amongst the outer Solar System objects. Their spectra are dominated by hydrogen and strong methane absorptions in the red and near infrared portions of the spectrum. Indeed, it is the methane absorption at red wavelengths that is largely responsible for the greenish visual appearance of these bodies. Although there are considerable uncertainties in the spectroscopic interpretative techniques currently in use, the present analyses suggest that the CH_4/H_2 ratio may be larger than the solar value by as much as an order of magnitude.

Evidence of other constituents in the planetary atmospheres is extremely limited. There is no information yet on the possible presence of helium, and any definite knowledge must await spacecraft observations from above the Earth's atmosphere or in the neighbourhood of these planets, or by direct entry measurements in the planetary atmospheres.

Ammonia has not been detected spectroscopically at visible wavelengths. Measurements in the microwave portion of the spectrum indicate that there may be two orders of magnitude less than expected in a mixing ratio based on solar abundances

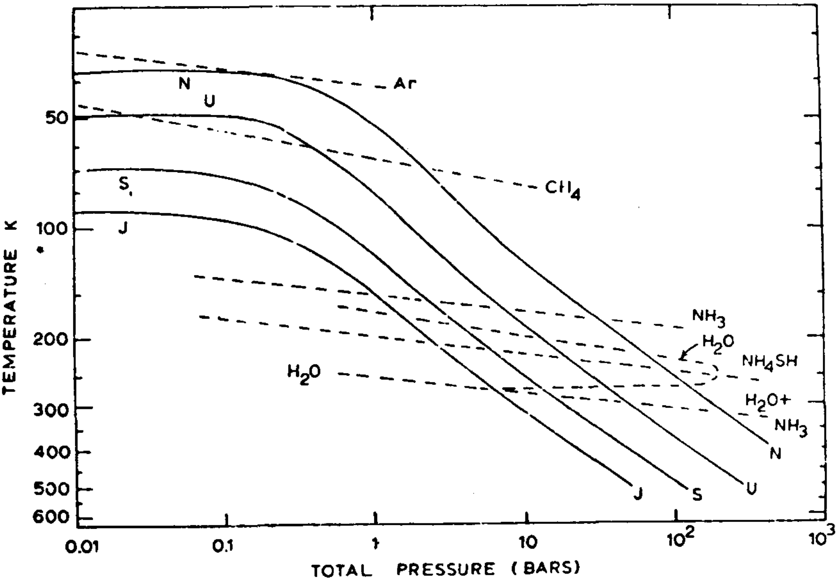


Figure 2. Atmospheric and cloud models of Jupiter, Saturn, Uranus and Neptune. The dashed lines give the condensation thresholds of CH_4, NH_3, NH_4SH, H_2O and aqueous NH_3 solution. Methane clouds are thought to be present on Uranus and Neptune (after Lewis, *Space Science Revs.*, **14**, 401-411 (1973))

in the Uranian atmosphere. It is possible that this depletion of NH_3 may be due to the formation of NH_4SH clouds at lower levels (see Figure 2). For this hypothesis to be correct requires the atmosphere to have a ratio of S to N which is enhanced relative to the solar abundance value. The presence of sulphur in the atmosphere is most likely to originate through H_2S, and its detection is still to be confirmed.

We have no knowledge of ammonia in the atmosphere of Neptune. It would be simple to assume as a first approximation, that the broad details of the Uranian properties would also apply to Neptune. But recent studies suggest this may not be a valid approach since these planetary atmospheres may have interesting differences to their minor constituent inventories. For although ethane (C_2H_6) has been found recently on Neptune, it has not been detected on Uranus. Does this suggest there may be differences in the structures of these planetary atmospheres? This would seem to be particularly remarkable since there is a close similarity in the basic properties of these planets (Table 1).

The observations of Neptune in the CH_4 band centred at 7.7 μm indicate a brightness temperature of about 115° K, which is much higher than the effective temperature of ~50° K. This radiation must be coming from a high level in the atmosphere, and this interpretation is consistent with the analysis of the occultation of BD-17°·4388 by Neptune, thereby indicating a substantial inversion in the stratosphere. But what is the mechanism responsible for this additional atmospheric heating? In the Earth's atmosphere it is created by solar heating by ozone. In the atmospheres of Jupiter, Saturn and Titan, the solar absorption of methane is the major heating mechanism for their respective inversions. Although methane is plentiful in the atmosphere of Neptune, sufficient additional heating can be obtained only if the atmosphere is supersaturated with this constituent. This would seem to be an unlikely explanation as a result of the obvious difficulty of maintaining the atmosphere in this enriched state.

Recent far infrared observations indicate an emission temperature of about 55° K, compared with a black body value of ~43-46° K for a planet at this distance. This clearly indicates that Neptune has an internal heat source. Could this property of the planet reduce the requirement of methane super-saturation? It would seem unlikely, since this additional heating would affect *all* atmospheric levels rather than in an isolated region.

There is, however, a major difference between the planetary systems, since near Neptune there is a large satellite Triton in retrograde orbit, which is in marked contrast to the Uranian system. Could there be a tidal interaction in which Triton heats the upper atmosphere of Neptune? Unfortunately, this is also an unlikely mechanism, since the most effective heating by this method would take place at very high levels in the atmosphere, and at altitudes much greater than the stratospheric region we are considering. Consequently, we are left in the difficult position of having determined a strong stratospheric inversion in the atmosphere of Neptune, which is inadequately explained by solar heating created by methane absorption and photochemical aerosols which are likely to be present at these levels.

But Uranus possesses a more complicated problem, for although there is an inversion at stratospheric levels, it is much weaker than that detected in the atmosphere of Neptune. The surface brightness of the planet is about 58° ± 2° K, suggesting that Uranus may not have an internal heat source. While this temperature is very similar to the radiating temperature of Neptune, the observations show the Uranus surface brightness to be at least an order of magnitude fainter at 8 μm, and about 50 times fainter at 12 μm compared with its planetary neighbour. This suggests that an efficient cold trap prevails in the atmosphere, since the methane to hydrogen mixing ratio must be much lower on Uranus to account for the weaker inversion. Furthermore, anomalies in the atmospheric structure of Uranus could result from its large polar inclination, since each hemisphere will spend a substantial period without sunlight once each Uranian year (Figure 3). It is apparent from this diagram that the north pole of Uranus is just turning towards us, having been turned away from the Sun for more than 40 years. The atmosphere will have cooled substantially in the

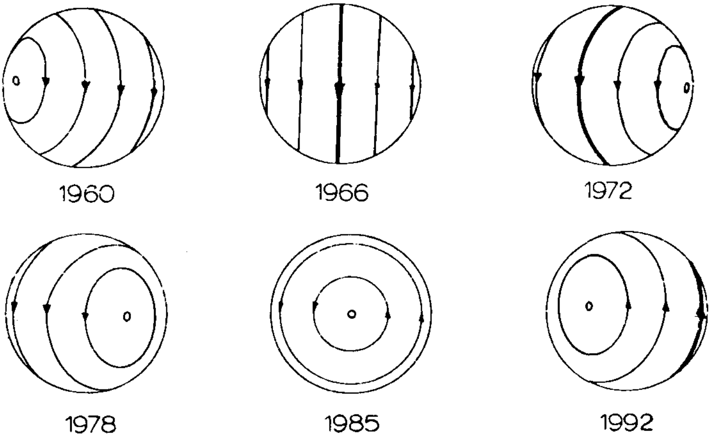


Figure 3. Sketches of the changing aspects of Uranus as a function of time (based on Alexander, *The Planet Uranus* (1965), Faber and Faber)

absence of meridional heat transport. Perhaps at this time the cold hemisphere of Uranus is efficiently absorbing the available solar radiation and thereby radiating less energy than it receives from the Sun.

Certainly, therefore, there are apparently major differences in the structures of the upper atmospheres of these planets. The variations in the temperature gradients in their stratospheric regions may indeed influence the detectability of the minor constituents. It will certainly be extremely important to patrol the thermal properties of these planetary atmospheres, to determine whether the Uranian properties vary with the total portion of the disk that is illuminated and heated. We may be certain that some interesting properties of this strange planetary atmosphere will emerge.

2.2. Planetary Rotation Rates

The rotation rate of a planet is a fundamental constant that bears directly on our understanding of the physical conditions and history of that body. For a planetary atmosphere it defines the dynamical region for the motions. Combined with the optical oblateness or the quadruple moment, the rotation rate constrains models of the formation and composition of the planet. For almost fifty years, the accepted rotational rate of Uranus was the work of Moore and Menzel, which gave a value of 10.8 hrs. Their work gave a value of 15.8 ± 1 hr for the rotation of Neptune, while Gunther obtained a value of 12h 43m 29s.

It has always been difficult to assess formally the accuracy of these original measurements. Certainly, the Uranus value was thought to be inconsistent with methane rich models of the planet which required a period of approximately 18 hours. The latest measurements are summarised in Table 2. The Uranus value has changed considerably from the work of Moore and Menzel. The value derived by Hayes and Belton and Trafton are certainly consistent with the modern values of the optical and dynamical oblateness of Uranus, and the theory of solid body rotation with hydrostatic equilibrium.

TABLE 2. *Rotation rates of Uranus and Neptune*

Planet	Rotation rate	Observers
Uranus	10h 50m ± 10m	Moore and Menzel (1930)
	15.57 ± 0.80h	Brown and Goody (1977)
	24 ± 3 hrs	Hayes and Belton (1978)
	23 ± 5 hrs	Trafton (1978)
Neptune	15.8 ± 1 hr	Moore and Menzel (1928)
	12h 43m 29s	Günther (1955)
	22 ± 4 hr	Hayes and Belton (1978).

The new observations for Neptune are less accurate owing to difficulties in making 'seeing' corrections. We therefore expect future observations to reveal a period for this planet in the range of 15 to 18 hours, which, interestingly, is consistent with the work of Moore and Menzel.

2.3. *Atmospheric Motions*

Uranus is the first planet so far from the Earth that dynamical activity manifested by clouds cannot be observed by ground-based observations. Consequently, we have no direct information about atmospheric motions. Our knowledge of the structure of the cloud layers, which would act as tracers of any motions is itself very limited. It is expected that a cloud of CH_4 droplets would form in the upper troposphere with a top at a level of ~4 atm, 90° K in the Uranus atmospheres. At deeper levels, layers of NH_3 cloud and NH_4 SH clouds are expected (see figure 2). While there is definite knowledge of a belt zone structure of the atmospheres of Jupiter and Saturn, there is far from unanimity on this subject when considering this possible property of the outer planets. Alexander suggested that when the equatorial regions of the planet are visible and the viewing excellent, two faint belts on either side of a bright zone are sometimes seen in larger telescopes. Antoniadi felt that the belts he observed appeared exactly parallel to the general plane of the satellite orbits and not tilted at about 20 degrees as other observers had reported. Dollfus remarked that the features he saw did not seem to be belts. Certainly, at the currently available Earth-based resolution, it is not possible to resolve this issue.

However, some recent, if somewhat perplexing, observations show unexpected differences in the behaviour of these planetary atmospheres. In a period of one year (1975-76) the reflectance of Neptune between 1 and 4 μm increased by a factor of 4, while the simultaneous measurements of Uranus showed a negligible change. Why should Neptune, the more distant planet, show evidence for apparent weather systems, but Uranus remains in a quiescent state?

TABLE 3. *Atmospheric Properties of Planetary Atmospheres*

	Albedo	Effective Temp T_e(°K)	Measured Temp T_M(°K)	Adiabatic Lapse Rate (°K/km)	Radiative Time Constant
Earth	0.30	256	256	~9.8	~60d
Jupiter	0.41	106	125±3	~1.8	~6 yrs
Saturn	~0.40	76±4	97±4	~0.7	~6 yrs
Uranus	0.34-0.5	55-58	58±2	~1.0	~600 yrs
Neptune	0.34-0.5	43–46	~55	~1.4	~2200 (yrs)

We have seen from our earlier discussions that these planetary atmospheres possess important differences in their basic properties. Neptune has an internal heat source, which will certainly affect the planetary meteorology. At regions of the planet where the internal heating exceeds the solar absorption radiation, we may expect convective processes to dominate as we find in the polar regions of Jupiter. But, we should remember that the observed change in the reflectance of Neptune, which may relate to a variation in the cloud structure, refers to a measurement of the *complete* planetary disk. Consequently, we must be observing a global-scale phenomenon, which is therefore difficult to reconcile with any suggestion of belt/zone structure of the Neptune atmosphere.

But why do we not observe similar changes in the atmosphere of Uranus? Since the planet does not seem to have an internal heat source, any motions in this planetary atmosphere would result from differential solar heating. However, in this distant portion of the Solar System, the incident solar radiation is comparatively weak. Furthermore, the illuminated portion of the disk will behave as a sink to the incident radiative energy as it emerges from the long period in darkness (see Figure 3). Consequently, these factors, coupled with a radiative time constant of about 600 Earth years, which is enormous compared with the planet's orbital and rotational periods of 84 years and about 22 hours, would suggest that rapid, large-scale dynamical variations are unlikely in the atmosphere of Uranus. However, a further important point emerges from this work. Patrols of the brightness of the outer planets have been used as a method to monitor the solar constant. The apparent variability of the planetary reflectivities may place in doubt the value of this work.

We have no idea of the possible small-scale motions that may be present. Observations with sufficient spatial resolution must wait for the availability of the Space Telescope and the planned Voyager flights to Uranus in 1986 and Neptune in 1989/90. In the meantime, we must continue simultaneously to monitor the radiative properties of these planets at all possible wavelengths to understand the similarities and differences of these planetary atmospheres, for we may be sure that unexpected and exciting results will emerge from such studies.

3. Conclusions

We have seen that the giant major planets which reside beyond the asteroid belt, form two distinct groups. Jupiter and Saturn have atmospheres whose composition closely resembles the Sun. Uranus and Neptune are a separate family, with less than solar proportions of the light, abundant elements, hydrogen, helium, and greater proportions of heavier elements. This division amongst the giant planets is, in itself, a major constraint upon theories to explain the origin of the Solar System.

However, the emerging picture seems to be even more complicated. Although Uranus and Neptune are similar in their large-scale properties of size, mass, albedo, rotation rate, major atmospheric constituents, they do seem to have important and unexpected differences. Neptune seems to have an internal heat source, a strong stratospheric temperature inversion, and a meteorological system capable of producing large-scale changes in the visible appearance of the planet which may be modifying the cloud structure. Uranus on the other hand, may not possess an internal heat source, so that only weak motions will prevail generated by differential solar heating, while a weak inversion is found at stratospheric levels. A major reason for studying planetary atmospheres is to gain insight and understanding of effects which are obscured and complicated by various mechanisms peculiar to the Earth's meteorology. It also provides a means of testing our understanding of physical processes in our environment different from that in which we have developed our original ideas. The atmospheres of Uranus and Neptune offer us a great challenge.

Acknowledgements

We acknowledge the permission granted by the Editor of *Icarus* to reproduce Figure 1, the Editor of *Space Science Reviews* to reproduce Figure 2, and Faber and Faber to reproduce Figure 3.

The story behind the discovery of the rings of Uranus

GORDON E. TAYLOR

'What was that . . . was there a tracker glitch . . . No . . . it's clearly duplicated in both channels'—A tape-recording of conversation on board the Kuiper Airborne Observatory on 10 March 1977, as the first unexpected dip in the photoelectric trace of Uranus passing in front of a star occurred. Later on, this dip was recognized as being caused by a ring around the planet. But this was only the (unexpected) culmination of many astronomers' work over the previous years—a truly international effort.

The fact that Saturn had a system of rings around it has been known for about three centuries. For almost the whole of that period it was believed to be unique in this respect. There were two exceptions to this rule. After his discovery of Uranus itself, William Herschel, in 1787 and again in 1789, suspected the existence of not one, but two rings around the planet, at right angles to each other. However, by 1798, further observations had convinced him that his earlier observations were erroneous. According to G. F. Chambers, *A Handbook of Descriptive Astronomy,* similar observations were made by Lassell, Challis and Bond of a suspected ring around Neptune. Again these observations were never corroborated so that until 1977 Saturn has appeared unique with its magnificent system of rings.

For many years now I have been interested in occultations of stars by the larger bodies of the Solar System—planets, satellites and minor planets. This was because the occultation technique offers, in principle, the most accurate method of determining the shapes and sizes of the occulting bodies. In addition, the position of the body at that time is determined to an accuracy far greater (normally at least an order of magnitude greater) than is obtainable by other means. Photoelectric observations of such occultations can also give valuable information about the upper atmosphere of the occulting body, if it has one. Such observations can also detect hitherto unknown components of double stars.

Unfortunately, the frequency of occultations of stars by planets is very low, particularly when compared with occultations by the Moon. Let us examine the relative frequency of occultations by the Moon to those by Uranus. The Moon, with a diameter of about 0°.5 (= 1,800″) travels 360 degrees in a month of 27.3 days. Because of parallax, observers on different places on the Earth's surface see the Moon against different background stars so the width of the track has to be increased by a factor of 5. Uranus, diameter only 4″, increased to say 5″ to allow for parallax, travels the same angular distance in 30,685 days. However, it does have a retrograde motion, unlike the Moon, so that we could increase the 360 degrees by a factor of 3. Thus, for the same limiting stellar magnitude the relative frequency of occultations by the Moon to those by Uranus is

$$\frac{1800 \times 5 \times 30685}{5 \times 27.3 \times 3}$$

a ratio of about 670,000 to 1. However, since the Moon is much brighter than Uranus the proportion of *observable* occultations is very much less.

The Smithsonian Astrophysical Observatory (SAO) Star Catalog, covering the whole sky down to a magnitude of +9 to +10, contains a quarter of a million star positions—an average of about 6 stars per square degree of sky. Allowing for the fact that for about 1/6 of the time Uranus is too close to the Sun for observation, we may calculate that on the average an observable occultation by Uranus occurs about every 12 years.

Although I started to search for occultations by Uranus in 1952, by comparing an ephemeris of Uranus with the positions of the stars in star catalogues, it was 25 years before success was achieved. That this interval of time was double the average value is probably due to the fact that Uranus was never near the galactic plane during those 25 years. The star concerned was SAO 158687, with a spectral type of K5 and a visual magnitude of +8.8. Thus its photographic magnitude was about +10. Therefore, relative to Uranus which has a photographic magnitude of about +6, the star was very faint and realizing that observations would be difficult with the equipment then available I published the predictions four years in advance (in 1973). This, in turn, enabled an extensive investigation of the spectrum of Uranus and also that of the star to be made—by both Carlson and Elliott and by Veverka and Millis who listed the most suitable wavelengths on which observations should be made.

The original prediction was that the occultation would be visible from the land areas surrounding the Indian Ocean; in fact, for any place where Uranus was above the horizon at the predicted time. I did not then expect any possible error in the position of Uranus relative to the star to be so large as to displace the track of the occultation off the face of the Earth. However, I suggested that we should use the close approach of Uranus to the star in January 1977 (two months before the predicted occultation on 10 March) to take photographs, measure the relative positions of the two objects and then refine the predictions.

The situation is shown diagrammatically in Fig. 1 (p. 180). Uranus passed about 0′.8 south of the star on 22 January, moving eastwards until it reached a stationary point on 15 February. Afterwards its retrograde motion brought it back to occult the star on 10 March. As Uranus was well south of the Equator, Southern Hemisphere observatories would have been best placed for these observations. In particular, observatories in Australia and South Africa were asked to take photographic plates.

By this time, several expeditions had been planned—French observers were going to Naini Tal, India, while U.S. observers were going to Perth, Western Australia. In addition, astronomers from Cornell University, Ithaca, N.Y., intended to use the Kuiper Airborne Observatory (KAO) flying westwards

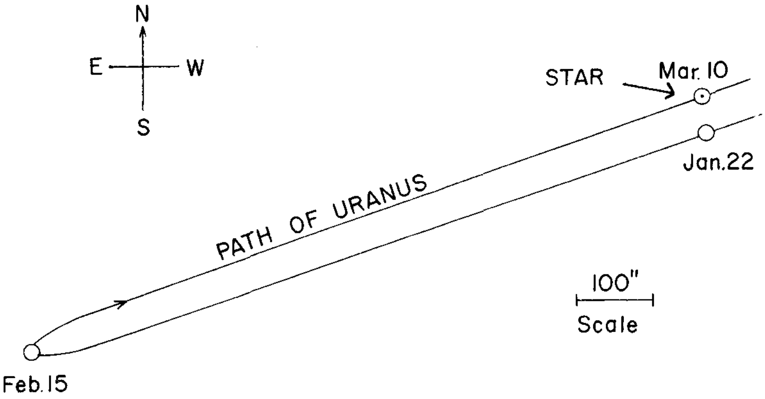


Figure 1. Path of Uranus relative to the star SAO 158687

over the Indian Ocean from Perth. It was this observatory which had made highly successful observations of the occultation of E Geminorum by Mars on 8 April 1976, and in particular was able, for the first time, to record a central spike on the photoelectric trace, caused by the focusing effect of the Martian atmosphere.

January came and went, while photographic plates were taken from observatories in Australia and the U.S.A. The results came in—and caused consternation! Measures of the plates taken at Sydney, Australia, showed that the star was far away from its catalogue position in one direction while Uranus was displaced from its ephemeris position in the other direction. Plates taken and measured at Perth gave an almost identical result. A revised prediction based on this new information showed one fact quite clearly—Uranus would not occult the star as seen from anywhere on the Earth. But plates had also been taken at Flagstaff, Arizona. A revised prediction based on the results from these plates showed that the occultations would now only be visible from part of the Southern Hemisphere of the Earth. In other words results from two observatories out of three indicated that no occultation would occur! Consternation is an understatement. I received a message from the U.S.A. which said, 'American astronomers are running around like chickens with their heads cut off' and 'we've already spent $200,000 on our expeditions'. Fortunately, they didn't threaten to sue! My reply was that I was sorry to hear about their obtruncated observers, but that now we could only wait and see. If I had been addicted to nail biting I would have been limbless long before the date of the occultation! The Americans went to Perth as planned and the KAO was re-routed to follow a track south-west from Perth towards the Kerguelen Islands. In France, Berezne, Lecacheux and Vapillon had specially constructed equipment ready to take to India. However, they decided to go to Johannesburg, South Africa, where the chances of seeing the occultation were slightly higher than at either Perth or from the aircraft. In the event, it was cloudy at Johannesburg.

Fig. 2 shows the situation with lines showing the northern limit of the occultation—(*a*) from the original prediction; (*b*) corrected using the Flagstaff plates; (*c*) corrected using the Perth plates; (*d*) corrected using the Sydney plates; and (*e*) which was the track as determined from the actual observations. It is important to realize how critical the situation was at the time. An error of only a tenth of a second of arc could alter the position of the limit by 1,300 km: or to put it another way, it only needed an error of 0″.5 to shift the limit from the Earth's equator to its pole.

Now the time of mid-occultation, should it occur, was fairly well determined being within a few minutes of 21 hours U.T. since the same values for this quantity were obtained from all the plates taken in January. But, since it was uncertain whether the occultation would take place at all, there was considerable uncertainty in the predicted times of the disappearance and reappearance phases, should they occur.

For example, a shift in the relative position of the star and Uranus of only 0″.1 would mean that the predicted duration of an occultation at, say, Perth would change from 0 to 20 minutes.

Although South Africa stood the greatest chance of being inside the track of the occultation there was always the risk of weather conditions there being unsuitable. Would the KAO get the occultation? Although not as far inside the track as

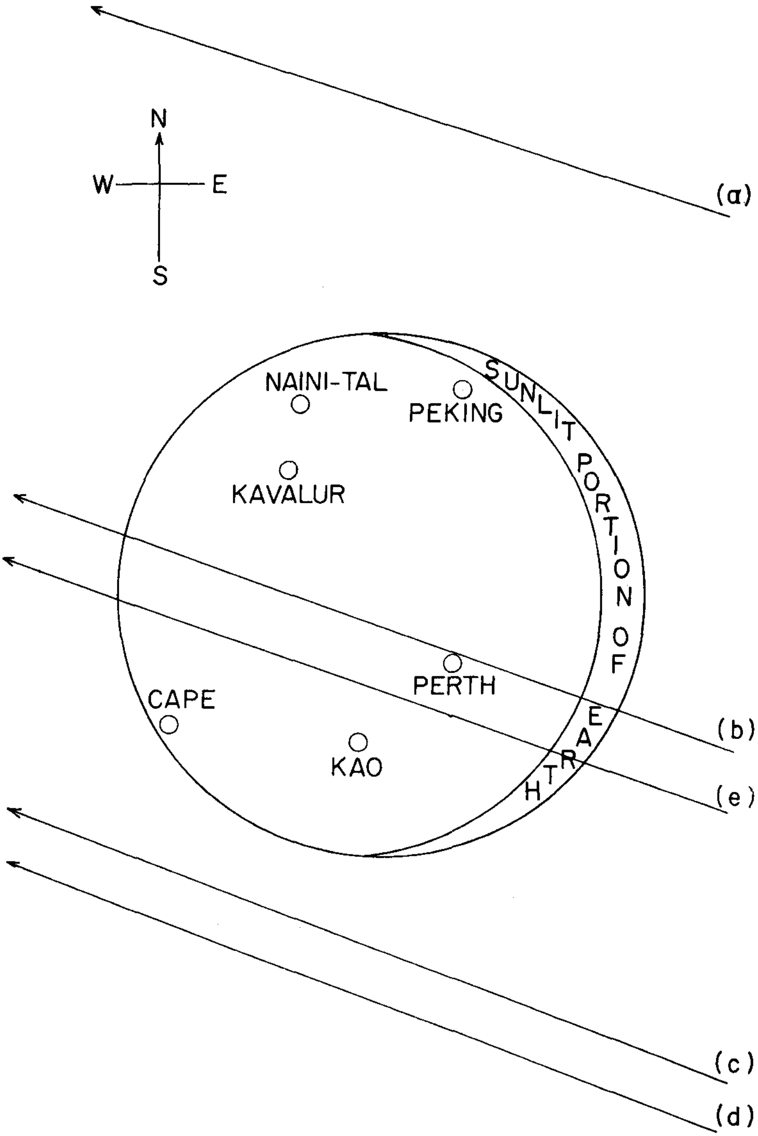


Figure 2. The track of the northern limit of the occultation as determined from various predictions (a)-(d) and in reality (e).

observers at the Cape of Good Hope the aircraft had the great advantage of flying at a height of 12.5 km, above the weather. The observing team onboard (Elliot, Dunham and Mink) had a team joke: 'If we didn't observe an occultation, we could use the data to put an upper limit on the optical depth of a hypothetical ring around Uranus.'

My own hope—of determining the diameter of Uranus from timed observations of the phases of the occultation made from widely spaced observatories was not realized. But, serendipity, there is no doubt that something far more interesting was discovered instead—the rings! As we all now know the observations turned out to be an outstanding success, apart from the unfortunate observers at Sutherland and Johannesburg who were foiled by the weather. For the record, the following observations of dips in the photoelectric records were made.

Observer(s)	*Place*	*Number of observations* (of rings)
Elliot, Dunham, Mink	KAO	10
Churms	Cape, S. Africa	6
Millis, Birch, Trout	Perth, W. Australia	5
Mahra, Gupta	Naini Tal, India	4
Bhattacharyya, Kuppuswamy	Kavalur, India	1
	Peking, China	2
		(of Uranus)
Elliot, Dunham, Mink	KAO	2

Fig. 3 (p. 184) shows the apparent path of the star behind Uranus and its rings, and also the location of the innermost and outermost rings which have been detected as well as the orbit of Uranus' innermost satellite, Miranda.

Of course, the very fact that there was such uncertainty in the predictions encouraged observers to start monitoring the event early, but I would not like to suggest that had the predictions been known to be accurate the rings would not have been discovered.

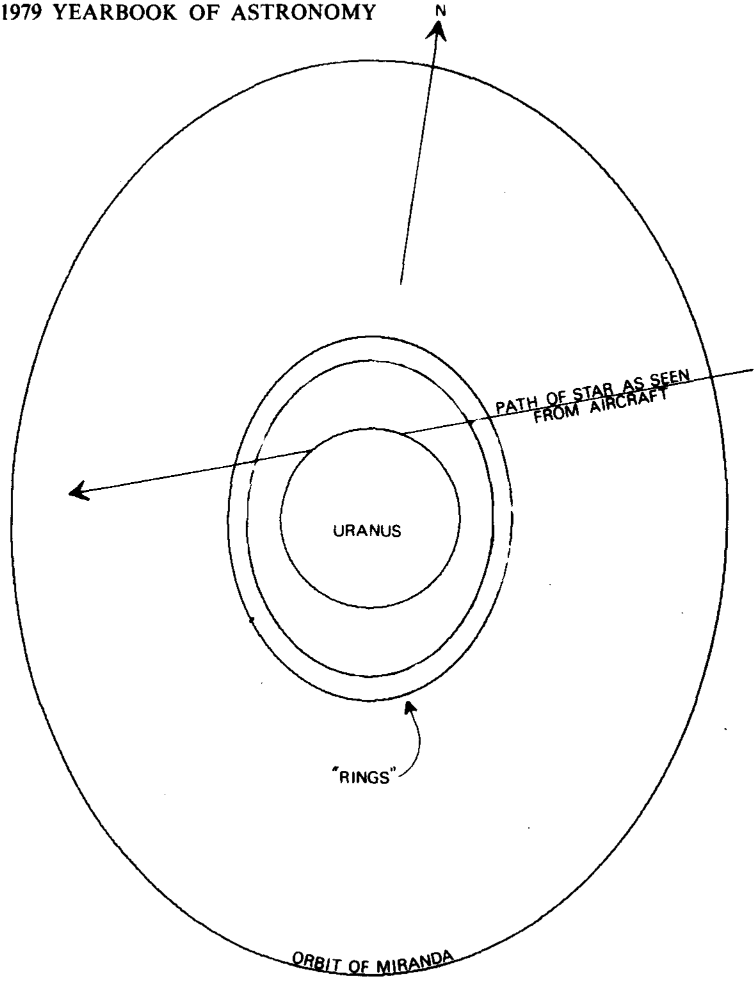


Figure 3. Apparent path of the star behind Uranus and its rings as seen from the Kuiper Airborne Observatory.

Details of the rings have been fully reported elsewhere, so they will not be repeated in detail. Briefly, however, we may state that five separate rings have been discovered. The rings appear to be composed of numerous small bodies <6 km in diameter. Fig. 4 (p. 185) shows the photoelectric traces obtained by the Kuiper Airborne Observatory.

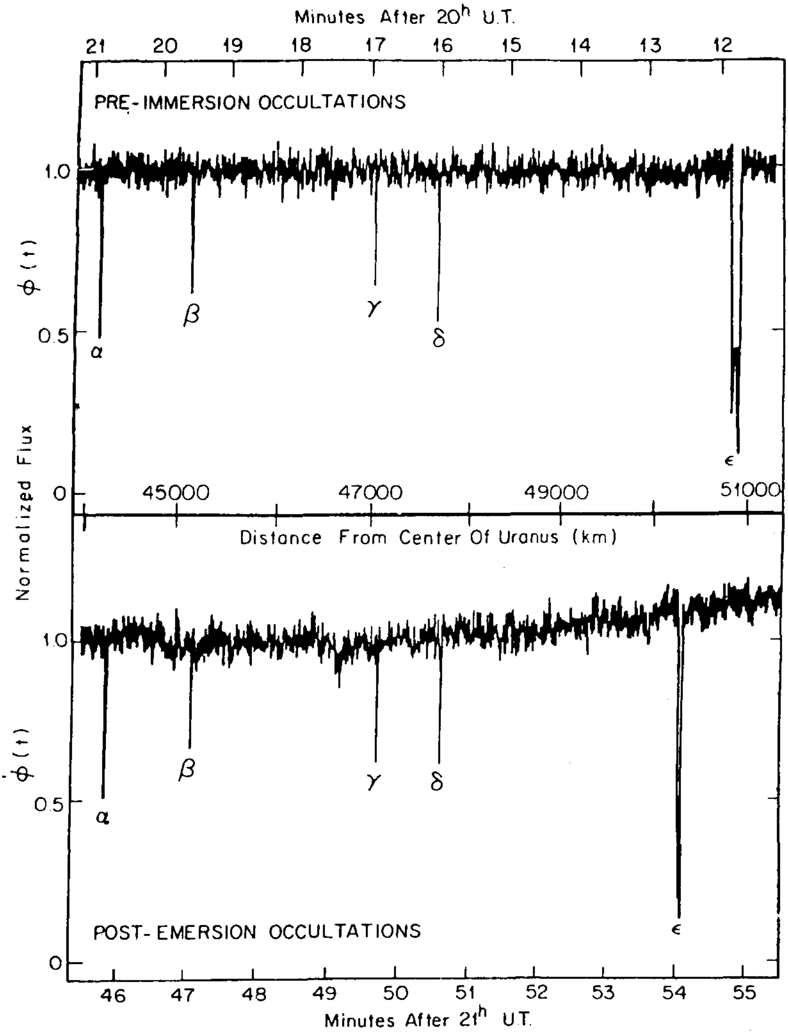


Figure 4. The actual photoelectric recordings of the occultations by the rings, observed onboard the Kuiper Airborne Observatory.

It must be emphasized that even now no one has ever seen or photographed these rings. Their existence is known only from the photoelectric records. We shall have to wait until January 1986 when the space probe Voyager is expected to pass close to Uranus. There is also the possibility that a large space telescope in orbit around the Earth might be able to obtain a photograph. The chance of photographing the rings will be greatest in the next decade, since the rings will be fully open around 1985, when the north pole of Uranus will be pointing almost directly towards us. The rings will not be seen edge-on until about the year 2007.

In the meantime, photographic plates are being taken of the area ahead of Uranus in the hope of detecting future occultations of faint stars. Klemola and Marsden have found a number of possibilities in the next few years but the brightest star occulted has a photographic magnitude of +12.2, two magnitudes fainter than SAO 158687.

The next occultation of the SAO star will occur on 25 June 1985 when it is expected that an occultation by the Rings will be visible from Africa, Europe and Western Asia. The star concerned is SAO 184819, visual magnitude 9.2, spectrum G5.

The 'Maunder Minimum' in Perspective

CICELY M. BOTLEY

Honour is always given when it is due. For the prolonged minimum of solar activity in the late 17th century was not discovered by E. W. Maunder but—as Maunder freely acknowledged—was first announced by F. G. W. Spörer in his paper 'Upon the Periodicity of Sunspots since the year 1618' (published in 1889). But it was Maunder who first brought it to the notice of British astronomers in 1890, and then later on in 1922.

The problem is still of great interest, and has been discussed recently by J. A. Eddy of Boulder, Colorado (who has very kindly sent me a preprint of his paper). The title links the period with the reign of the 'Sun King' Louis XIV, 1643-1715. Note, however, that by the time that Louis was growing old the Sun was recovering its youth!

It must be remembered that in the late 17th century conditions were not the same as they are now. There were many observers of the Sun in western Europe, but none had a record of continuous observation such as had been attained earlier by Scheiner and Hevelius; they were light-years from the subsequent dedicated work of Schwabe.

It cannot be contested that observations of at least large spots were relatively rare before 1700, and there may well have been a relative absence of active groups of the kind normally producing flares. On the other hand, the solar cycle was not absolutely suppressed. Eddy's diagram shows two relatively active periods, 1650-1660 and 1670-1680; two less active ones, 1660-1670 and 1680-1690; and a very marked 'low' in 1690, followed by a dramatic rise which is confirmed by the History of the French Academy. 'Since 1695, for example, up to 1700 none were seen. Since 1700 our histories have been full of them; this continued up to 1710, when none were seen.'

Neither is it true that auroræ were entirely absent. Edmond Halley said that he never saw an aurora until 1716, and that there had been none since 1623 (actually the 1623 'aurora' was probably a bolide!) but this was a personal experience only. During Halley's lifetime there had been auroræ or 'lights in the air' in 1676, 1680 and 1685; the latter occurred just before the Battle of Sedgemoor, and was recorded by Macaulay and (very poetically) by Dryden. In Scotland during 1691 auroral displays seem to have been regarded as normal, at least during the visit of the exiled James II to Edinburgh in that year; he and his suite were astonished, but his hosts were unperturbed. And when James was four there had been a great stir in London due to an aurora—indeed, so much so that the situation was exploited by political agitators, who issued a pamphlet which was considered so inflammatory that it was effectively suppressed. It was not until 1951 that D. J. Schove brought it to notice in a paper delivered to the British Astronomical Association. Schove also pointed out that between 1656 and 1661 there were reports from as far geomagnetically south as Japan.

That most distinguished woman astronomical writer, Agnes M. Clerke, also declared that 'by the middle of the century polar lights had virtually died out everywhere except perhaps in the north of Scotland'. Probably she relied mainly upon Fritz's great catalogue, which, however, had its limitations as to information. Today, we have the catalogue of F. Link for the relevant century. This shows clearly that auroræ were regularly reported from Central Europe throughout the period, though with diminished numbers, reports since 1645 being only about 30 per cent of those for the previous forty-five years. Many of these auroræ were active, with rays, but apparently only two had coronæ which may well have been indicative of flare activity. There were only two reports from southern Europe, one being rather doubtful and the other not very far south. Mediterranean observations are useful inasmuch as they provide a very sensitive index of solar activity—particularly, of course, of geomagnetic storms.

J J. de Mairan (1678-1771), perhaps the first to determine auroral periodicity, found peaks in 1686 and 1710—the latter possibly when the Maunder Minimum was ending, or had actually done so. It is also important to note that C^{14} observations indicate that solar activity was low.

Eddy has made much of the brightness of the solar corona. Hooke, with Pope (the Gresham Professor) and others observed the partial eclipse of 22 June/2 July 1666 (depending upon which calendar style is used) through Boyle's 60 ft. focus telescope. The report states: '. . . there was perceived a little of the limb of the Moon without the disk of the Sun which seemed to some of the observers to come from shining atmosphere about the body either of the Sun or the Moon'.

Eddy gives observations for 1652 (during the early stage of a cycle), 1698 (minimum) and 1706 (just after maximum). These eclipses—all total—are described as 'dull' or 'mournful', and often as 'reddish'. In 1706, this would have been due to the chromosphere. The Sun was apparently reverting to normal, and Plantade and his colleagues at Montpelier seem to have seen a bright inner corona extending out to 4 degrees; evidently they had good weather. At the 1715 eclipse, Halley and Louville gave characteristic descriptions of a normal minimum-type corona, with plumes and extensions and a complete ring of chromosphere. The state of the sky was not given.

There is, moreover, evidence that the brightness of the corona is not bound up with the state of the Sun. During the joint Royal Astronomical Society/British Astronomical Association visit to Sweden in 1954 (of which the writer was a member), the corona was not simply of minimum type, but the much rarer type only seen with an undisturbed Sun; despite a veil of cirrus cloud, both the inner corona and the extensions shone forth, and were bright enough to give pink and green diffraction rings. Yet during that expedition the late J. Jackson, then H.M. Astronomer at the Cape, commented that during an eclipse which he observed from South Africa, doubtless under very favourable conditions, gave a corona which was 'flat like a photograph', though at that time the Sun was very active. Minimum-type coronæ, as in 1976, may have streamers generated by prominences, while undisturbed coronæ show only the solar field and equatorial extensions.

It is also worth mentioning that from a study of a drawing by Hevelius, Eddy considers that the Maunder Minimum may have been connected with an acceleration of the rotation of the solar equator. And in 1711, W. Derham, a Fellow of the Royal Society, commented that 'there are doubtless great intervals when the Sun is free [from spots]'.

Research has shown with certainty that the Maunder period was but one of a series. This has been deduced by Schove from reports of auroræ which can be traced back to the 5th century B.C. There is a tendency for auroræ to recur in 'odd' centuries.

Are there still records for this interesting period available but hidden in archives? Those from Italy would be very valuable. That spots were being observed at this time is shown by the plate depicting the Sun in the series by Donati Creti of Bologna (1671-1749). This is now in the Vatican picture gallery, Room XIV, and shows elegantly dressed young men in 1700-style costume observing the Sun; there is a large inset, showing the Sun—with spots on it.

References

Arago, F. *Astronomie,* 3 (22), p. 592ff.

Eddy, J. A., *et al. Solar Physics,* Vol. 51, p. 3ff (1976). "The Maunder Minimum" *Science,* **192,** p. 1189-1202 (1976).

Fritz, H. *Das Polarlicht* (1881).

Link, F. Catalogue of Auroræ Observed in the West, 1600-1700 (Prague, 1962).

Maunder, E. W. "The Prolonged Sunspot Minimum", 1645-1715." *Journal Brit. Astron. Assoc.,* Vol. 32 (4), p. 140-145 (1922).

Schove, D. J. *Journal Brit. Astron. Assoc.,* Vol. 61, p. 38ff (1951). *Jnl. Geoph. Res.,* Vol. 60, p. 127-146 (1955).

Spörer, F. G. W. *Astr. Ges. Vitrjschr.,* **22** (1887); and *Astr. Bul.,* **6** (1889).

Brighter than a Million Suns

DAVID A. ALLEN

Chile, January 1972

I was using a 40-inch telescope at Cerro las Campanas. The equipment at the Cassegrain focus was an infrared photometer, a device which simply measures the brightness of stars at wavelengths several times that of normal light. In 1972, the southern skies, accessible from Chile, were little-studied at infrared wavelengths, so the thrill of exploration pervaded the observing run.

I set the telescope to a sixth magnitude star in the constellation Carina and put my eye to the eyepiece. I still vividly recall that moment, for the field of view is perhaps the most beautiful you can see through a telescope of that size. The whole field was filled with a misty, green luminescence—a great cloud of excited gas, woven into veil-like curving streams. In the lower right, a keyhole-shaped dark patch clearly sat in front of the misty nebula. Inky black it was, as though something opaque was stuck to the back of the eyepiece. But as I pressed the slow-motion buttons it moved with the star field: the keyhole was in fact a massive cloud of dust and gas at a distance of several thousand light years, obscuring the nebula behind it. At the top of the field of view lay a loose cluster of stars, mostly blue. And there, in the centre of the field, was the star I wanted to observe. But quite unlike a star it was—more a celestial poached egg, a round orange blob a second or two across and set in a frothy white nebula.

I manipulated the poached egg into the appropriate position on the graticule; I pulled a lever which tilted a mirror so that its light no longer reached the eyepiece but landed on the infrared detector. Immediately the dome was filled with a loud, electronic buzz. I knew the reason even before I walked over to the mountain of electronics that inevitably accompanies the infrared observer at his work. The buzz was emanating from the chart recorder: the pen, which normally drew a wiggling red line down the middle of the chart, was pinned against the right-hand edge of the paper, plaintively complaining that too strong a signal was coming down the snaking black cables from the detector.

So the poached egg is a very bright infrared source. Sadly I wasn't the first to discover this fact: Gerry Neugebauer and Jim Westphal, of the California Institute of Technology, had done so four years previously. In fact, they had shown that at the infrared wavelengths of 10 and 20 μm this is the brightest source in the sky aside from solar system objects. What is this distinguished object? It is known as Eta Carinæ.

Now, Carina is in itself a large constellation, but it is only a part of the disbanded Argo Navis. When Argo was broken up, the Bayer letters were retained with the individual stars, so that α and β went to Carina, γ and δ to Vela, and so on. We are concerned with η Carinæ, formerly η Argûs, and since Eta is the seventh letter of the Greek alphabet, it is a fair bet that η was about the seventh brightest star in Argo. But so large a constellation as Argo, straddling a rich section of the Milky Way, must have had more than seven bright, naked eye stars; indeed from the magnitudes of δ , ϵ , ξ , θ , ι , and κ Argus we can deduce that η Argus was thought by Bayer to be 3rd magnitude. Why, then, is η Carinæ now barely visible to the naked eye, even from so clear a place as the Andean foothills of Chile? To answer this we must delve into a little history.

A Brief History of η Carinæ

I believe that Bayer's *Uranometria* offers the first estimate of the magnitude of η Carinæ; this is usually quoted as 4th despite the argument above. In any case, in the late 17th century the star was rated 4th magnitude by Halley. It was soon shown to be variable, meandering irregularly between 2nd and 4th magnitudes. Nobody was particularly disturbed by this behaviour, since variable stars were pretty well known by then. But people began to take notice when it exceeded its normal brightness range in the early 19th century. In December 1837, John Herschel found it to have crossed the zero magnitude point, and five years later it became the second brightest star in the sky at about magnitude -1.0.

Having reached its peak, seemingly satisfied with second brightest, it began its protracted descent to one-thousandth of its peak brilliance, and it has stayed between about 6th and 7th magnitude ever since.

The nebulosity that reminded me of an egg white, but which is usually called the *homunculus* because of its shape, was not noticed until about 70 years ago when Innes catalogued what appeared to him to be companion stars embedded in a faint nebula. It soon became apparent that these were knots of nebulosity moving radially outwards from the central orange object. The homunculus is now about 10″ across, large enough for a fairly acurate determination of its expansion and hence of the date of its genesis. This date does not appear to be the same for all portions of the homunculus, and this suggests that there were several ejections in different directions spread over a few years. The average date, determined by Bob Gehrz and Ed Ney from recent photographs, is 1835—just the time that the greatest brightening occurred. Gehrz and Ney took some rather attractive colour photographs of η Carinæ: these were reproduced on the July 1972 cover of *Sky and Telescope.*

The homunculus is not the only nebulosity associated with η Carinæ. A faint outer ellipse was discovered by David Thackeray on photographs taken with the Radcliffe 74-inch telescope in South Africa. This too is expanding. And η Carinæ lies in the midst of the Carina Nebula, NGC 3372 (the central portions of which are shown on the cover of this *Yearbook*). NGC 3372 is a giant cloud of ionized hydrogen, the second brightest nebula in the sky (after Messier 42 in Orion), and easily visible to the naked eye despite lying at about four times the distance of the Orion Nebula. NGC 3372 is excited by a large number of hot, blue stars, some of which formed the spangled cluster which I saw in the 40-inch view, lying to the north of η Carinæ.

When a star undergoes such remarkable antics as had been shown by η Carinæ, the services of that most valuable of all astronomical equipment, the spectrograph, are brought to bear on it. The first spectrum of η Carinæ was taken in 1892: this showed the star to be a normal supergiant of spectral type F5, quite similar to the star Canopus which, half a century earlier, it had outshone. Three years later another spectrogram was secured, and a most dramatic change was found to have occurred. Instead of the dark Fraunhofer absorption lines of a normal stellar spectrum, η Carinæ showed a series of bright emission lines. The strongest of these were due to hydrogen, but in addition there was a great number of lines of once-ionized iron, plus a few more lines of chromium, nickel, titanium, copper, nitrogen and sulphur. So drastic a change within a period of three years is in itself remarkable, but is made more so by the fact that since 1895 this spectrum has remained virtually unaltered. Another surprising aspect of this spectrum is the absence of lines due to oxygen, one of the most abundant of elements and one which usually features prominently in the spectra of nebulæ.

The Distance of Eta Carinæ

In documenting the remarkable properties of this star it is now necessary to consider its distance. Here we get on to uncertain ground. Distance determination in astronomy is always difficult and unreliable, and this is particularly so in the constellation of Carina where we happen to be looking directly along the inner spiral arm of our galaxy, so that there are stars and nebulæ at a whole range of distances.

The most reliable estimate of the distance is that for the cluster of blue stars, Trümpler 16, which illuminates NGC 3372. Even here, however, different researchers have come up with values ranging bebetween 3,500 and 12,000 light years. The most recent (and hence, hopefully, most reliable) values tend to be the lower, so I will adopt 6,000 light years as the best guess. In addition to this uncertainty of almost a factor of two, there is still debate about whether η Carinæ does lie in Trümpler 16 and NGC 3372 rather than in front of or behind them. Gehrz and Ney estimated the distance by assuming that the outward expansion of the homunculus was at the velocity inferred from its spectrum by Thackeray. They derived 6,800 light years, with a fair amount of uncertainty. This seems to confirm that we are using the right sort of distance.

Now consider that in 1843 η Carinæ was the second brightest star in the sky. Sirius, the brightest, is a mere 9 light years away. Even Deneb, the most distant first magnitude star, is only 1,500 light years distant. To compete with these, η Carinæ must have been an extremely luminous object. We can estimate its total luminosity and find a value about six million times that of the sun. Six million times . . . not only is this very much brighter than conventional novæ, but it exceeds by almost a factor of ten the most luminous star known, S Doradûs in the Large Magellanic Cloud.

Today, of course, η Carinæ appears much fainter. However, it now pours out most of its energy at infrared wavelengths. The mechanism is well understood. The homunculus is a shell of gas and dust that surrounds the star. Because we view the central object through this dust, it appears dimmed. The dust absorbs the visible and ultraviolet radiation of the star, but in so doing it is heated. Hot dust radiates in the infrared, but it radiates only as much energy as it absorbs from the star. Thus in our determination of the luminosity of the central object we must include the contribution from the infrared radiation. When we add this we find that η Carinæ is as luminous now as it was in the 1840s: it still radiates several million times as much energy as the sun. Since 1843, η Carinæ has output about as much energy as is released by the most energetic supernova explosion, or is emitted by most stars in their entire lifetimes.

The Central Star

It is particularly unfortunate that the major outburst of η Carinæ occurred only a few decades before the spectrograph became readily available. A better knowledge of the outburst itself, and particularly of the star before its outburst, would greatly have assisted our understanding of the star. As it is we can only examine the object in its present state, largely veiled behind a curtain of dust. What, then, can we say about it?

First, we can determine its luminosity, as I have just described. We also can estimate its temperature in a number of ways. From the emission lines we have one value, since stars of different temperatures will ionize atoms to different extents. From the colour of the star we get another estimate. The deep orange hue is due largely to the hydrogen emission, but we can make allowance for this and for the other emission lines. We can also correct for the reddening effect of the dust in the homunculus. A third value comes from X-ray satellites. Very hot stars are X-ray sources, but η Carinæ has not been detected, so this gives an upper limit to its temperature. These three methods indicate that the star has a temperature of around 25,000 degrees Kelvin (about the same Celsius). This is not exceptionally high: many of the very luminous stars in our and other galaxies are much hotter.

The temperature uniquely defines how much energy is radiated from each area of the star's surface. Knowing the total luminosity we can thus deduce its surface area, and from this its diameter. We find that η Carinæ is something like ten times as big as the sun. Again this is not unduly large—the red supergiants such as Betelgeux are several hundred times the diameter of the sun.

In all probability it is the mass of η Carinæ which is extreme. We don't know, for there is no direct method of determining this parameter. If its density were the same as that of the Sun, its mass would be one thousand times as great. But this is certainly an overestimate: it can be shown theoretically that so large a mass of gas trying to form a star inevitably breaks up into smaller portions. In fact, it is difficult for a star to form with a mass much larger than 100 times that of the Sun. η Carinæ may be somewhere near this limit. Theory also predicts that so massive a star is unstable and will intermittently or continuously eject some of its mass. In particular, there is a rule known as the Eddington limit (after the former

Cambridge astrophysicist) which states the maximum allowable luminosity for a stable star of given mass. At 100 solar masses, the Eddington limit is four million times the luminosity of the Sun. If a star begins to generate nuclear energy at a higher rate than this, it will blow off its outer layers. η Carinæ is probably very close to its Eddington limit.

But what of the F supergiant spectrum of 1892? At that date, η Carinæ appeared to be a normal star with a surface temperature of about 8,000 degrees K. How do we reconcile this with its present state? The answer is that the 1892 spectrum was not of η Carinæ. I don't mean that someone observed the wrong star. What I mean is that at the time the shell of material which had been thrown off 50 years earlier, and which eventually formed the homunculus, was opaque. We couldn't see through it to the central star. We saw merely the surface of a cocoon of gas which happened to have cooled to 8,000 degrees K. Within the next few years, by 1895, the shell thinned out sufficiently, due to its expansion, for us to see through to the underlying star with its emission-line spectrum. The transition from opaqueness to transparency can occur quite quickly, and once the central object is visible, the shell need not affect the spectrum at all. Thus, no change in the spectrum would necessarily have been expected between 1895 and the present.

The Nature of Eta Carinæ

We cannot yet say with certainty what η Carinæ really is. We need additional observations, either through the adoption of novel techniques or by some clever use of existing instrumentation which has not yet been devised. Or we need the star to show some type of change comparable to that of the last century.

But I cannot end a *Yearbook* article on so negative a note; here is a credible guess—for which I claim no originality—which appears to fit the observations. At the centre of the largest clouds of gas in our Galaxy an unusually massive knot tried to collapse to form a star. It succeeded quite recently: perhaps only a few tens of millennia ago. As the star proceeded to produce energy at its natural rate, it became unstable and began a series of minor outbursts. Each outburst involved only a slight increase in its total luminosity—maybe a factor of two or less—but it was enough to cause a fraction of its outer layers to be thrown off as a shell. One such shell was ejected over a period of a few years around 1840. The previous shell has almost disappeared; all that remains of it is Thackeray's elliptical nebula.

As the gaseous shell expanded, it cooled until eventually dust grains could condense within it. We know from the infrared observations that some of the dust is composed of silicates (like sand and stony meteorites) as is the dust around cool red stars such as Betelgeux. Silicates use up a lot of oxygen in their formation, and this might amount to an explanation for the striking deficiency of oxygen lines in the emission spectrum of η Carinæ. In any case, it was the formation of a translucent screen of dust, more than the change in luminosity following its outburst, that caused the star to fade during the second half of the 19th century.

This is one possibility. However, we cannot reject an alternative model in which η Carinæ is a binary star. It is now well established, due primarily to the work of Bob Kraft of the Lick Observatory, that novæ are binary stars. The nova outburst is triggered because gas becomes sucked out of one star by the gravitational attraction of the other. The luminosity, rise in magnitude from minimum, and the time scale of the outburst and subsequent fading are parameters which differ from star to star for reasons which are not entirely understood. Typically, a nova rises in brightness very rapidly, develops the spectrum of an A or F star (that of the cooling shell), and proceeds shortly after maximum to an emission spectrum. This then proceeds through a series of spectral changes as the star fades back to minimum. The first stage of the emission spectrum usually resembles the spectrum of η Carinæ.

Some novæ progress much more slowly through this sequence than do others. Nova Pictoris (1925) and Nova Delphini (1967) are examples. Some, the so-called slow novæ, take decades. RR Telescopii erupted in 1944 and has faded only a few magnitudes since. RT Serpentis (eruption 1909) and, more recently, V1016 Cygni and HM Sagittæ have behaved similarly. There are objects called symbiotic stars which seem to freeze the fading spectra of slow novæ: these may be undergoing the same processes as the slow novæ, but even more gradually. No examples of any of these types of object are anywhere near as luminous as η Carinæ, but that alone does not preclude η Carinæ from being a uniquely slow and bright specimen of mass transfer in a binary system.

For η Carinæ is a unique object.

Supernovæ in History

F. RICHARD STEPHENSON

To quote a well-known saying of Henry Ford, 'History is bunk'. Whatever the reader's views on this remark, does it apply to the history of astronomy? Or, to put the question in another way, are the observations made by the ancients of any value at the present day? Many readers might be of the opinion that historical astronomy is purely an academic study. However, there are a few scientists active in the field of 'applied historical astronomy' who think otherwise.

Astronomical observations recorded in history which are of special interest at the present day fall into four main types: eclipses, sunspots, comets and supernovæ.

The earliest known record of an eclipse of the Sun goes as far back as 1375 B.C. This is described on a clay tablet found in the ruins of the ancient seaport of Ugarit, in present-day Syria. Observations of eclipses, which are fairly regularly reported from different parts of the world since this time, give us valuable information about the rotation of the Earth and motion of the Moon in the past. They indicate that the length of the day is increasing slowly, but fairly steadily, at about 1/50 second every thousand years. A further result is that the Moon is gradually drifting away from the Earth at approximately 4 cm a year. The cause of both of these changes lies mainly in the tides. Modern studies using the laser reflectors which the Apollo astronauts placed on the Moon have already detected its recession from the Earth and in a few years should yield very accurate results. However, pride of place must go to the ancient observations.

Sunspots were 'discovered' telescopically by Galileo Galilei in 1610, but more than 1,500 years before they were a familiar phenomenon to Chinese astronomers using only the unaided eye. In 28 B.C, a 'black vapour as large as a coin' was seen within the Sun, and between then and the invention of the telescope almost 150 such sightings were reported. At first, these were almost exclusively the prerogative of the Chinese astronomers, but after about A.D. 1100 the Koreans became just as enthusiastic. Particularly large spots or spot groups can be seen fairly readily with the unaided eye near sunrise or sunset or through thin cloud, and it seems that this is the method which the Oriental astronomers used. There is no evidence that they used filters of some kind to dim the Sun or looked at its reflection in water or pitch. Probably because of the belief by Aristotle that the Sun was perfect, there are virtually no pre-telescopic sightings of spots from the West.

Even the Oriental sightings tend to be very sporadic; certainly they are of little use in studying the well-known 11-year cycle in the past. However, exciting developments have recently taken place with the discovery that at several lengthy periods in history—notably A.D. 600-800, 1300-1350, 1400-1600 and 1650-1700 (all only approximate) virtually no sunspots were seen. This apparently decreased activity is confirmed by carbon-14 studies. This leads to the intriguing speculation that over the long term the Sun is a variable star.

Brilliant comets have caused fear and wonder throughout the world for thousands of years. However, most of these objects are of very long period—perhaps a million years—and once having faded they are never seen again. So far, only one bright periodical comet has been discovered. This was first identified by Edmond Halley and rightly bears his name. Most of the time, Halley's comet, which has an average period of 76 years, is invisible even in the most powerful telescopes. However, for a few brief months around perihelion (closest approach to the Sun) it becomes a striking object with a remarkable tail. The appearance in A.D.1066, about the time of the Battle of Hastings, is well known. However, modern research into observations recorded mainly in Far Eastern chronicles has made it possible to trace almost every perihelion passage of Halley's comet for more than 2,000 years.

Finally we come to supernovæ. These are spectacular exploding stars which shine out with a brilliance of perhaps a thousand million Suns for a few months before fading into relative obscurity. Supernovæ are particularly remarkable because they leave behind a long-lasting remnant in the form of a powerful radio source. This can persist for tens of thousands of years. More than a hundred of these supernova remnants (SNRs) have been discovered by radio astronomers, and a number of SNRs have been found to emit visible light and X-rays. Supernovæ are believed to represent the catastrophic explosion of a more massive type of star which has reached the end of its active lifetime. The star has by this time acquired a very dense core of helium and heavier elements which is surrounded by a diffuse atmosphere of enormous extent. The supernova explosion is triggered off by the sudden collapse of the core, which releases vast amounts of energy. A shock wave is generated which literally blows the outer atmosphere off into space.

The envelope continues to expand and acts as a powerful source of radio waves thousands of years after the immediate effects of the explosion have ceased to be visible. If the core is of moderate mass—somewhat heavier than the Sun—a rapidly rotating superdense neutron star is formed. This may be observed as a pulsar. If the core is unusually massive, however, complete collapse to a singularity—a black hole—may occur.

Supernovæ occurring in other galaxies are discovered very frequently (several times a year) with the aid of some of the world's most powerful telescopes, notably at Mt Palomar and Asiago (Italy). However, not one of these huge celestial explosions has been seen in our own Galaxy since as long ago as A.D. 1604 (i.e. before the invention of the telescope). There appear to be two main reasons for this. Supernovæ do not occur very often in any particular galaxy—a reasonable estimate of the frequency in a galaxy the size of our own is as low as one per century. Additionally, the Solar System is located right in the plane of the Milky Way where most of the obscuring dust lies. It is quite possible that more than one supernova could have been *visible* in our Galaxy during the past 400 years but escaped detection through loss of light in interstellar space. Oddly enough, there seems to be a far better chance of detecting a supernova in an external galaxy than in our own. Because of its small *apparent* size, a whole galaxy can be scanned regularly using a powerful telescope. This is one of the main reasons why extragalactic supernova searches are so remarkably successful—some 500 supernovæ have been discovered to date.

As yet it has not proved possible to detect the radio waves from these very distant supernovæ which lie far outside the Milky Way. In fact, all the SNRs which have been discovered up to the present time lie either in our own Galaxy or in the two Magellanic Clouds. These clouds are satellites of our own Galaxy and so are fairly local. Thus, we have an anomalous situation: on the one hand, numerous supernovæ have been discovered in other galaxies, but as yet no extragalactic SNRs have been found; on the other hand, no galactic supernovæ have been observed for nearly four hundred years, yet many galactic SNRs are known! This, in brief, is the explanation of why historical studies of supernovæ are so important.

The identification of supernovæ recorded in history with SNRs detected by radio telescopes is arousing special interest at the present time. From the radio data, an *estimate* of both the distance and age of a SNR can usually be obtained. It is then possible to compare with historical records and decide whether a certain SNR is at least a plausible candidate as the remnant of a historically recorded new star or whether the two are incompatible.

As might well be imagined, early descriptions of new stars show tremendous variation in quality. Some of the accounts of the temporary stars of A.D. 1572 and 1604 are very precise and leave no room for doubt that both objects were supernovæ. Many earlier reports mention only the briefest of details; in such cases, it is frequently impossible to determine the exact nature of the star—whether supernova, nova or comet. The usual criteria applied to select supernova candidates from amongst historical records are low galatic latitude and lengthy period of visibility—say six months or more. When a supernova first shines out, its brightness reaches a maximum fairly quickly (a matter of days or weeks), but afterwards the fading is very slow and regular. Again the galaxy has a flattened disk-like structure so that because of their immense distance from us (of the order of 10,000 light years) supernovæ tend to appear very close to the galactic equator.

Exhaustive research into historical records has revealed no more than seven potential galactic supernovæ, appearing in the years A.D. 185, 393, 1006, 1054, 1181, 1572 and 1604. All of these were seen for at least six months and all appeared within a few degrees of the galactic equator. In every case, it has proved possible to deduce reasonably good locations from the original observations and these are in excellent agreement with the positions of SNRs of acceptable age and distance.

Let us take a brief look at the 'case histories' for each of the seven supernova candidates listed above, summarising the records available and outlining how the identifications with SNR were made.

On 7 December, in A.D. 185, Chinese astronomers observing from the capital of Lo-yang noticed a strange 'guest star' low down in the sky near the asterism of *Nan-mên*—the 'Southern Gate'. The new star remained visible for as long as 20 months (the brief report overlooks heliacal setting and rising). *Nan-mên* consisted only of the two bright stars α and β Centauri, the two brightest stars in Centaurus. These were never more than a very few degrees above the horizon at Lo-yang even when on the meridian. Thus, although a direct reference to the brightness of the star is not mentioned, to have remained visible for so long in such unfavourable circumstances the star must have been exceptionally brilliant. Indeed the magnitude at maximum has been estimated at −8. This is not unreasonable, for when first detected the star was fairly close to the Sun and would have risen in the dawn glow. The star was described as 'multi-coloured' and 'scintillating', both of which are in keeping with a very bright object at low altitude.

A supernova has an absolute magnitude of around −18 or

–19 at maximum (depending on the type) so that assuming the new star was indeed a supernova, the distance would be in the region of 5,000 light years. Only one known SNR could possibly fit such a distance and be of about the right age. This is G315.4–2.3 (the numbers refer to galactic co-ordinates). The position of this object lies within about 2 degrees of the recorded position of the new star—perhaps as good agreement as could be expected. This fairly young SNR has an optical remnant (RCW 86) which has many similarities with the Crab Nebula. Quite recently, it has also been discovered to emit X-rays.

After A.D. 185, the event of A.D. 393 is something of an anticlimax. In February or March of this latter year, another guest star was discovered—also in China. By this time, the capital had moved farther south to Nanking. The very brief report merely states that a 'guest star appeared within (the asterism) *Wei*' for some eight months. The term 'guest star', also used to describe the A.D. 185 object, was usually applied by Oriental astronomers to a new star-like object. This normally meant a nova or a supernova. Because of the rather long period of visibility, there seems to be a good chance that we are again dealing with a supernova. Additionally, the asterism *Wei* (the tail of the celestial Dragon in Oriental astronomy, but the tail of the Scorpion in the West) lay right across the galactic equator. A rough estimate of the magnitude of the new star at brightest is perhaps around zero (similar to Arcturus). This suggests a distance of some 15,000 to 20,000 light years from us. Two youngish SNRs which are only about 0.5 degrees apart (G348.5 + 0.1 and G348.7 + 0.3) both fit the Chinese description rather well, but unfortunately there is no way of deciding between them at present. So far, both objects have only been detected at radio wavelengths.

Still proceeding in chronological order, we have to wait more than 600 years before we encounter the next probable supernova which was visible from Earth. At the end of April, in A.D. 1006, there shone out a new star which surpassed all others, both before (as far as recorded history goes) and since. Its brightness was so astonishing that both in Europe and the Arab lands, spectators overlooked prejudices (on Aristotelian doctrine the heavens are immutable) and recorded vivid descriptions of it. As usual, the Chinese astronomers diligently watched the star, which also attracted much attention in Japan.

The new star, which appeared close to β Lupi, remained visible for at least two years—possibly several more. In both East and West, observers remarked on its extreme brilliance; this is all the more remarkable because of its extreme southerly situation. At St Gallen in Switzerland it was said to 'dazzle the eyes'. In both Egypt and Syria the star was independently compared with the Moon in brightness. The Chinese astronomers stated that it 'shone so brightly that objects could be seen clearly by its light'. These various remarks are compatible with an apparent magnitude around –9 or –10.

Fortunately, the Chinese positional description is excellent, and careful investigation has enabled the celestial co-ordinates to be fixed to within about a degree. The galactic latitude is unusually high for a SNR (about 15 degrees). This is typical of a relatively nearby object, as is also the great brilliance. A fair estimate of the distance is no more than about 3,000 light years. At such a high galactic latitude SNRs are very uncommon, and it turns out that only two SNRs could *possibly* correspond. One is the very ancient (perhaps 100,000 years old) Lupus Loop, a large arc of very low surface brightness. For this source, the positional agreement is not particularly good. The other SNR is G327.6 + 14.5, a young remnant lying very close to the area designated by the Chinese observers. Both distance and age are, in fact, quite acceptable, and this star is probably the earliest established supernova with an unquestionably reliable remnant (pending further research on the A.D. 185 object). It is interesting to note that G327.6 + 14.5 has lately been detected at both visible and X-ray wavelengths.

Next we come to the very famous star of A.D. 1054. This has attracted far more attention than it deserves, mainly because of the discovery of the pulsar associated with it. In actual fact, the star never became much brighter than Venus, so that among the possible supernovæ discussed here the 1054 object ranks as fairly average! This perhaps explains the complete lack of reference to the star—which unquestionably was a supernova—both from Europe and the Arab dominions. In China, the new star was assiduously observed, and it was also sighted in Japan. Beginning on 4 July, in A.D. 1054, the Chinese astronomers kept it in sight for 23 days in daylight, followed by a further 21 months at night. The period of visibility would be interrupted by conjunction with the Sun (the star appeared near the ecliptic in Taurus), but there is no mention of this—as in A.D. 185.

The recorded position has aroused much controversy; in China, the star was reported to be south-east of ζ Tauri, whereas, in actual fact, the Crab Nebula lies about a degree north-west of it. However, such a mistake could be readily made in summarising the original observations for inclusion in the *Sung-shih* (the dynastic history of the time). In any case, no other SNR lies in the vicinity, and no other *possible* supernova has ever been reported as appearing near here. Thus, if we doubt the association of the Crab Nebula with the new star of A.D. 1054, we have a lot of explaining to do! What is particularly encouraging is that both the expanding optical filaments and the pulsar indicate an age of the right order.

The Crab Nebula is an intense source of radio waves (G184.6-5.8), and is also strong at X-ray wavelengths. It is generally believed that most of this radiation is supplied by the pulsar; without it the Nebula would probably be a rather feeble, fairly typical SNR. No other remnant of a historically observed supernova is known to contain a pulsar.

We have just seen that two supernovæ were observed within a period of less than 50 years. Not quite 150 years after the A.D. 1054 outburst, a third *possible* supernova appeared, this time in the constellation of Cassiopeia, near ϵ Cassiopeiæ. Unlike its two predecessors, this was only visible for six months and so was probably never very bright—zero magnitude seems a fairly good estimate. Once again there is no record from Europe or the Arab lands, but fortunately both the Chinese and Japanese astronomers observed it rather carefully.

The new star first appeared on 6 August, in A.D. 1181. Its position was described in detail by both the Chinese and

Japanese astronomers, but unfortunately the best description is somewhat ambiguous. The star appeared very close to one of the central stars of the long straggling asterism *Ch'uan-shê,* but which one is not stated! Locating the remnant required quite a piece of detective work, since all of the stars of *Ch'uan-shê* are very faint. However, only one SNR adequately fits the indicated position, and this lies very close to the brightest star of *Ch'uan-shê* (magnitude + 5.2). The SNR catalogued as G130.7+3.1 is very distant—some 25,000 light years away—and must be located near the extreme edge of the Galaxy. However, since light loss in this direction is likely to be smaller than towards the galactic centre, an apparent magnitude of zero for the original explosion seems quite realistic.

An age of about 800 years fits G130.7+3.1 fairly well. Very recently, the object has been detected at infra-red wavelengths after a search for several years. At the present time, the source is regarded as a very plausible remnant of the A.D. 1181 star.

A gap of four centuries brings us to the two most recent galactic supernovæ; these appeared in A.D. 1572 and 1604. By this time, Chinese and Japanese astronomy had gone into something of a decline, whereas in Europe this was the age of some of the greatest pre-telescopic astronomers. It is interesting to note that although the two stars, which were unquestionably supernovæ, were seen only 32 years apart, they actually exploded—in different parts of the Galaxy—about 10,000 years apart!

The new star of A.D. 1572 was first detected in early November near κ Cassiopeiæ, not very distant from the 1181 star. It remained visible for about 18 months and was seen throughout Europe where it was circumpolar (and so never set). It attracted the attention of many European astronomers, but Tycho Brahe, who was not quite 26 years of age when the star first appeared, gave by far the most detailed account. He measured the position in relation to some of the brighter 'fixed' stars of Cassiopeia, and this allows its position to be calculated within a very few minutes of arc. Tycho also estimated the brightness from time to time, and this allows a surprisingly good light-curve to be drawn. The light-curve *proves* that the star was a supernova (of Type I). The supernova reached a brightness similar to that of Venus (magnitude about –4) and was visible by day.

Tycho's measured position lies well within the boundary of the young SNR listed as G120.1+1.4. This is a fairly strong radio source, but at the rather large distance of about 20,000 light years. It is also a feeble emitter of visible radiation as well as an X-ray source.

What Tycho Brahe did for the supernova of A.D. 1572, his pupil Johannes Kepler did for the A.D.1604 star. This appeared on 9 October, in 1604, in the southern constellation of Ophiuchus (not far from η and ξ Ophiuchi), and remained visible for fully a year. The star appears to have become rather brighter than Jupiter, say around magnitude –2.5 at maximum.

The position measured by Kepler and also by David Fabricius (the discoverer of Mira Ceti) was even more accurate than that of Tycho Brahe. This lies very close to the centre of the young SNR numbered G4.5+6.8. There is clearly no problem of identification here! Kepler estimated the changing brightness of the object, and once again it is clear from his findings that the star was a supernova of Type I. What is particularly interesting is that—for some reason—Korean astronomers were also diligently comparing the brightness of the supernova with planets and stars. Combining their estimates with those of Kepler leads to a more accurate light curve.

G4.5+6.8 lies at a distance of about 30,000 light years away—in the region of the galactic centre. However, it is situated well off the plane of the Galaxy above the dust clouds. This is why it was so bright. If it had been much nearer the plane it would have escaped detection completely. The SNR was discovered in visible light more than 30 years ago, but so far has eluded detection at X-ray wavelengths.

So ends our historical survey. Supernova studies obviously form a very important aspect of historical astronomy. What of the future? The discovery of early observations of other supernovæ is rather unlikely, for the literature has been well searched. However, a new galactic supernova could well appear at any time. It may be very much dimmed by interstellar dust, but there is a good chance that it could rival or outshine the brightest stars. We now have the instruments to make a detailed investigation at a variety of wavelengths. Let us hope that another galactic supernova appears soon!

The author gratefully acknowledges the help of Dr. David H. Clark.

Journey to the Centre of the Galaxy

HEATHER COUPER

In an increasingly bizarre Universe, we fondly regard our own Galaxy as a haven of peace and tranquillity. Not for us the violent birth-pangs of the remote quasars; or the disruption suffered by an exploding radio galaxy. Our Milky Way is among the lucky ones: a huge, slowly wheeling whirlpool of stars and gas, glowing serenely in the vastness of space.

But can we be so sure? There is growing evidence that many otherwise 'normal' galaxies have violence in their hearts. Observing in 1943, the young American astronomer Carl Seyfert noticed that there were a few spiral galaxies whose nuclei did not appear as smooth ellipsoids of old, red stars, but as dazzling, star-like points. To date, more than a hundred of these 'Seyfert galaxies' have been discovered. They are galaxies in a state of turmoil. Massive clouds of hot gas race away from their centres, with speeds up to 8,000 km per second (18 million mph), while their nuclei shine so brilliantly that they drown the rest of the galaxy in their glare. And this enormous output is not constant: over periods of months many Seyfert nuclei fluctuate markedly in brightness. As well as helping us to pinpoint the processes at work in the hearts of these galaxies, this behaviour tells the astrophysicist something of the size of a Seyfert nucleus. Astonishingly, it cannot be more than a few light-months across—comparable in size with the Solar System (including the most distant comets). Yet this region is giving out as much energy as our entire Galaxy of some hundred thousand million stars!

Powerful as they are, Seyferts cannot rival the awesome fury of the distant quasars, which are a hundred times more energetic. But astronomers think that they are observing the same kind of process in each case, whatever it may turn out to be. What's certain is that both types of object contain an exceedingly tiny and energetic central source, which is able to heat and eject enormous masses of gas.

How much energy is involved, and does it present any physical problems? Current evidence suggests that quasars are very young—a million years old, at most—and so the total energy output over their short lifetimes does not raise too many difficulties. But Seyferts are middle-aged galaxies, and it is physically impossible for them to have been pouring out energy at their present rates since they were born. Such activity, however, need not be continuous. We know that Seyferts vary in their light output; and other active galaxies (radio galaxies in particular) show signs of repeated, intermittent explosions. Seyfert activity could be a 'passing phase' which many galaxies go through from time to time.

It would be interesting to know what sort of galaxy is likely to 'go Seyfert'. The majority of the Seyferts we observe are spirals; and these Seyfert galaxies make up some 10 per cent of the total number of giant spiral galaxies—galaxies like our own. Now let us turn that last bit of information around and ask: is it possible that *all* giant spirals spend 10 per cent of their lives in a Seyfert phase? In particular, has our own Galaxy suffered in this way; or can we predict if it will become active? To find the answers to these questions, we must turn our attention away from the Seyferts, and towards the nucleus of our Milky Way Galaxy itself.

Seeing through the murk

Living as we do in the outer parts of the Galaxy, we might expect to be treated to a grandstand view of our nucleus. But we have reckoned without the dimming and obscuring effects of the interstellar dust, which literally chokes the disk of our Galaxy like a cosmic smog. When we look towards our galactic centre—10 kpc (30,000 light years) distant, in the direction of Sagittarius—we find that the dust along the line of sight

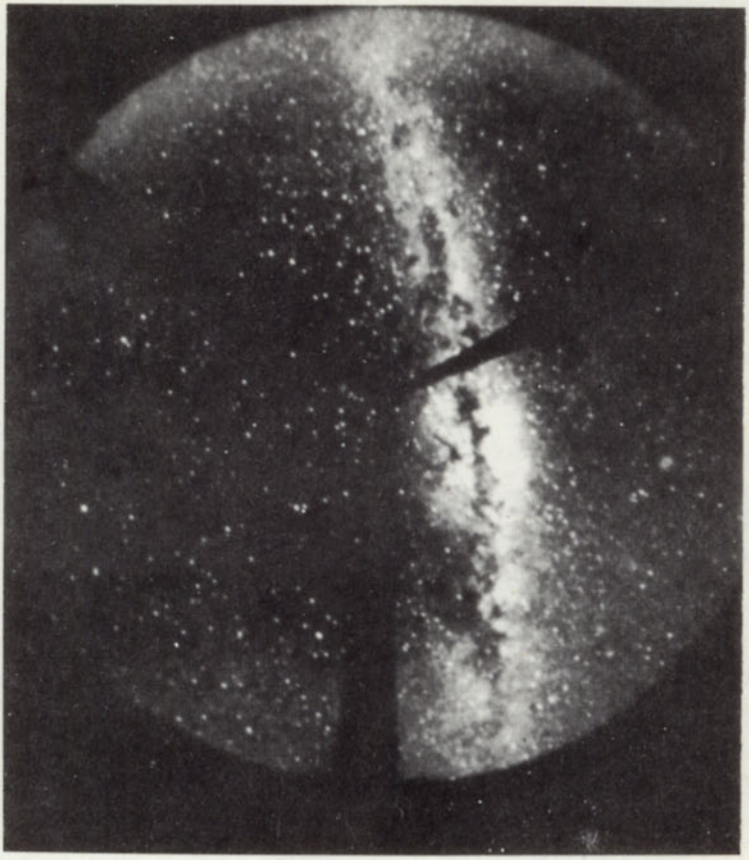


Figure 1 'All-sky' photograph of Milky Way, centre obscured by dust lane.

produces some 28 magnitudes of absorption (see Figure 1). To put it another way, light from whatever lies at our galactic nucleus is dimmed a hundred thousand million times!

But why restrict ourselves to light? Today's astronomers have a vast range of wavelengths at their command, from ultra-short gamma-rays to radio waves tens of metres long. Wavelengths longer than light—infra-red radiation and radio waves—actually penetrate the murk which dogs the optical astronomer, and can reach us right from the very heart of our Galaxy.

Our journey begins almost thirty years ago, when the young discipline of radio astronomy was providing its first tentative observations. A general background of radio waves had been picked up from the Milky Way—the disk of our Galaxy—and a number of smaller, more intense sources had also been detected. Early instrumental accuracy was poor, and the positions of these 'point sources' were only known to the nearest few degrees. They were named after the constellations in which they appeared, in alphabetical order of intensity. Two sources—Sagittarius A and B—lay in the general direction of the galactic centre.

By the end of the 1950s, radio astronomy techniques had improved dramatically. In particular, Dutch radio astronomers had discovered that the cold hydrogen gas threading the disk of our Galaxy—neutral hydrogen, or H I—emits a radio spectral line at a wavelength of 21 cm. From the intensity of the line, astronomers could find the density of the gas; from the slight shifts in wavelength (caused by the Doppler effect) they could measure its velocity. Even its distance could be estimated, by assuming a 'model' for the rotation of our Galaxy. Radio astronomers were now in a position to map our Galaxy out to distances well beyond the reach of optical techniques.

Mapping the Galaxy

Dutch and Australian radio astronomers collaborated to produce the first H I maps of the Galaxy. The gas, concentrated into arms, clearly revealed a complex spiral pattern; and it also demonstrated that most of the arms were rotating smoothly about the galactic centre.

But Jan Oort, working in Holland, had noticed a few features which did not square with this simple picture. In 1957, he discovered a spiral arm which, although circling the galactic centre, also had a significant velocity towards us. At the same time, he picked out another, fainter arm beyond the galactic centre which appeared to be racing outwards with a velocity of 135 km per second. These two arms—the 3 kpc arm (named

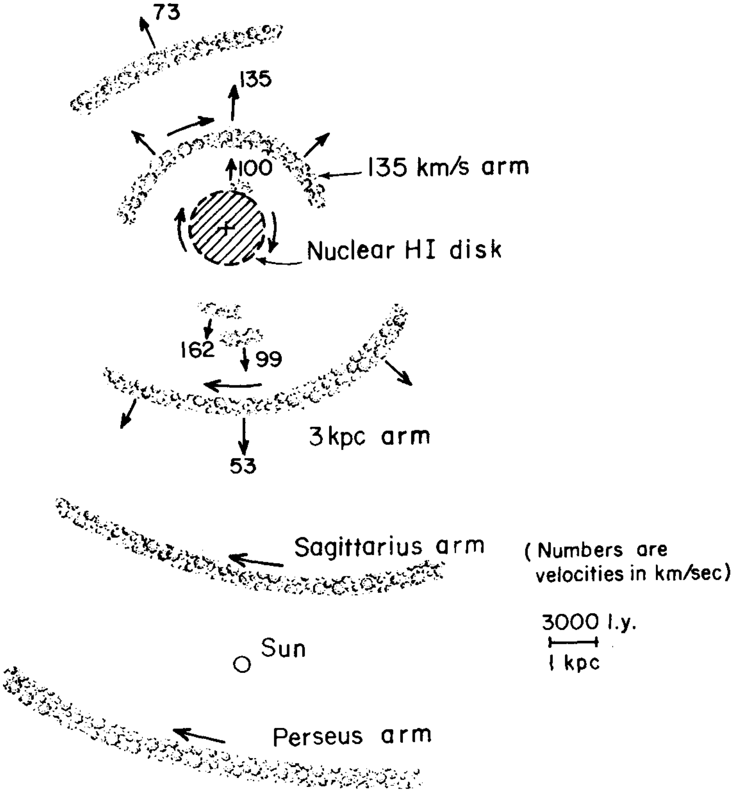


Figure 2.

after its estimated distance from the galactic centre) and the +135 km/s feature—were clearly showing signs of expansion away from the galactic centre.

The following years saw further refinements in radio astronomy methods, and the consequent discovery of many smaller 'expanding' features. Some were clearly parts of rings or arms; but others appeared to be clouds or even jets of gas, moving away from the galactic centre at quite steep angles to the plane (see Figure 2).

The evidence strongly suggested that an explosion had once occurred at the centre of the Galaxy. Oort had even observed that the region within the 3 kpc arm was poor in gas, as if swept

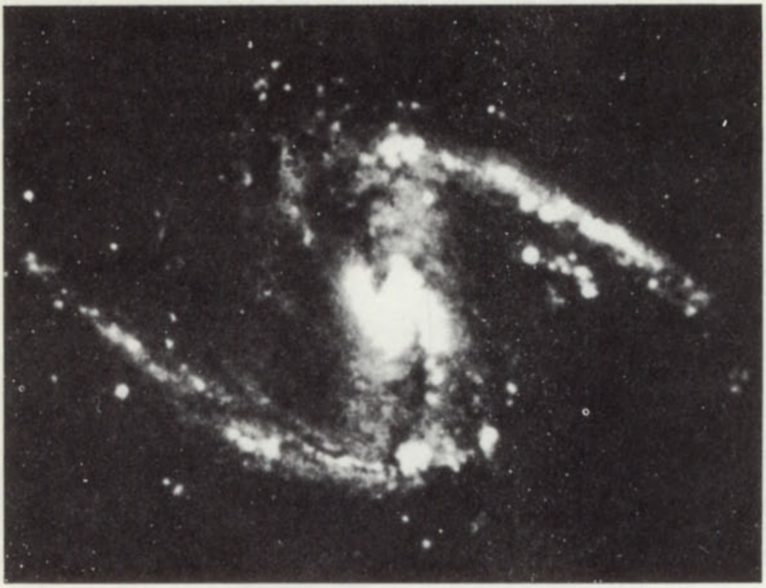


Figure 3 Photo of a barred spiral galaxy.

clean by the passage of an outward-moving arm. But in the early 1960s, before the discovery of quasars, this was a bit much for many astronomers to take. Surely, there had to be another explanation?

In fact, there were two. One suggestion was that the clouds were 'resonance' features, oscillating back and forth around stationary points determined by the gravitational field of the Galaxy. There were other astronomers, however, who believed that the 'expanding' motions arose from the ever-changing orientation of a bar-like distribution of mass at the galactic centre, such as we see in the so-called *barred* spiral galaxies (Figure 3). If the bar were slightly tilted above and below the galactic plane, it could even explain some of the highly inclined gas motions observed.

Which of the three hypotheses was correct? The only course available was to put each to the test by means of further observations. And so, twenty years ago, astronomers found themselves on the road to the centre of our Galaxy.

The nuclear disk and molecular clouds

As we have already mentioned, the density of hydrogen decreases inside the 3 kpc arm. But Jan Oort discovered that towards the galactic centre it suddenly rises again, forming a thin, uniformly rotating disk some 1,500 pc (5,000 light years) across. (This 'nuclear H I disk' is shown in Figure 4, which is drawn to a scale exactly ten times larger than Figure 2. With each subsequent figure, we shall increase our scale a further ten times.)

Before discussing the complex region at the centre of the nuclear disk, let us return to radio astronomy for a moment.

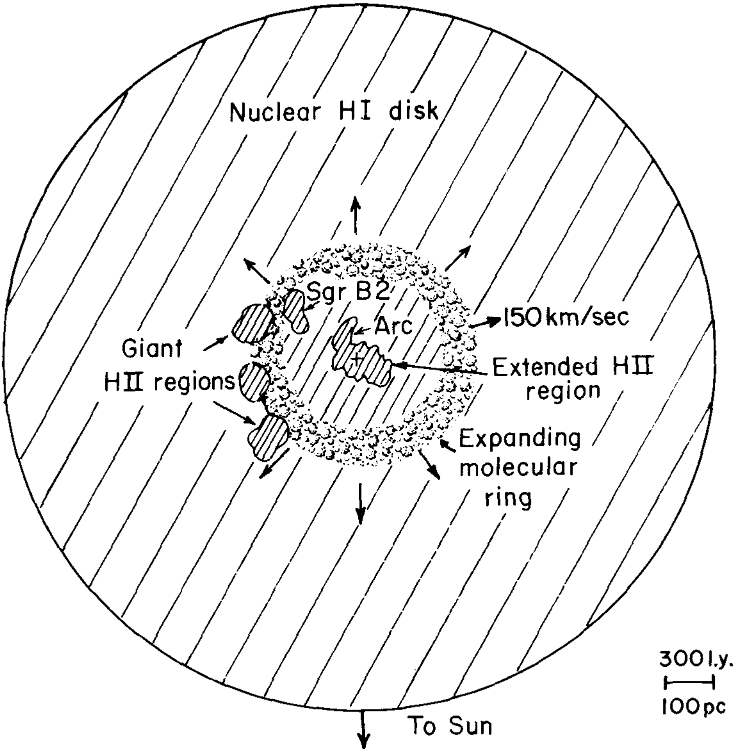


Figure 4.

Advances in electronics have meant that today's radio astronomer can pick up many more radio spectral lines besides the familiar 21 cm hydrogen line. A lot of these are in the millimetre and centimetre wavelength range, and they arise from the changing spin of molecules (groups of atoms joined together). The region surrounding the centre of our Galaxy has recently been found to be exceedingly rich in such molecules, including carbon monoxide, water, ammonia, formaldehyde and ethyl alcohol. (The discovery of the last has prompted several wits to remark that there simply must be a bar at the galactic centre!)

All these molecules are located in dense, cool clouds, which are arranged in a ring embedded in the relatively hot nuclear disk. The cool molecular clouds jostle with giant H II regions—clouds of hot hydrogen gas many times bigger than the Orion nebula—which also sit around the ring. The whole ring measures some 380 pc (1,200 light years) in diameter, and slowly rotates about the galactic centre. More importantly, it is also expanding outwards—at a velocity of 150 km/s.

We now have some rather puzzling observations to explain. There are the 3 kpc and '+135 km/s' expanding arms; a stable disk of hydrogen in perfect circular rotation within; and farther in still, another expanding feature—this time, a ring of molecular clouds. How do these observations square with our three hypotheses? The resonance model does not appear to fit well, because the molecular ring is not at a resonance point. Equally, we would not expect to find a smoothly rotating disk sandwiched between two expanding features if there were a bar at work. And so, we are left with today's 'best-buy' model for the origin of these expanding features: that of expulsion from the galactic nucleus.

We must continue on towards the galactic centre to search for further clues. But before moving on, let us quickly look at Sagittarius B2, which lies just inside the molecular ring. It was one of the first few dozen 'point sources' to be discovered by radio astronomers, as we mentioned earlier, and it is certainly a unique object in the Galaxy. Perhaps best described as a cross between a molecular cloud and a giant H II region, Sgr B2 is far

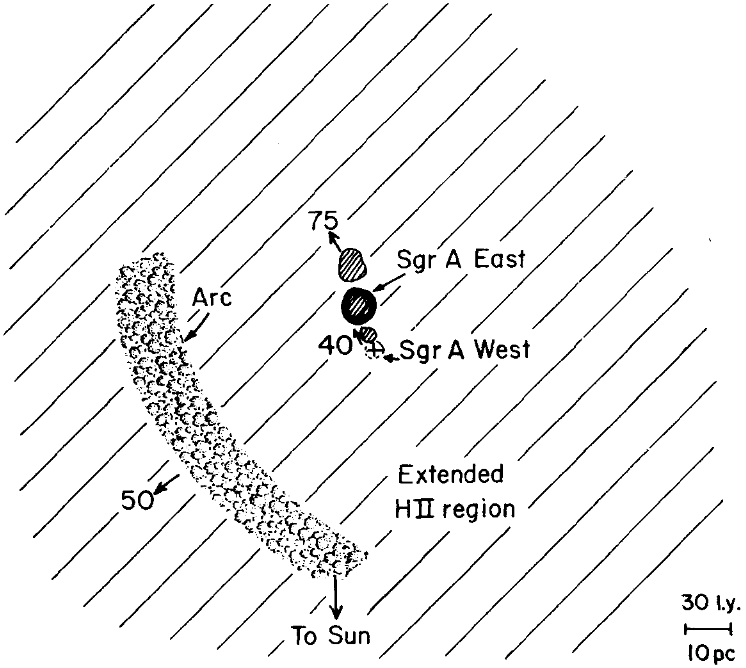


Figure 5.

bigger than either. It contains at least seven individual H II regions, each as big as the Orion Nebula. Its dense gas clouds are thick with dust, and rich in all species of molecules. In fact, every type of molecule discovered in our Galaxy has also been found in Sgr B2!

Sagittarius A

Moving up in scale by a factor ten (Figure 5), we home in on an extended H II region at the centre of the nuclear disk. Radio astronomers can detect a number of features in this small region, notably the Arc—an aptly named dense H II region which seems to be moving away from the centre—and Sagittarius A, which, we recall, was one of the first radio sources to be identified with the centre of our Galaxy. On this scale, we can just see that Sgr A consists of two components; but we must

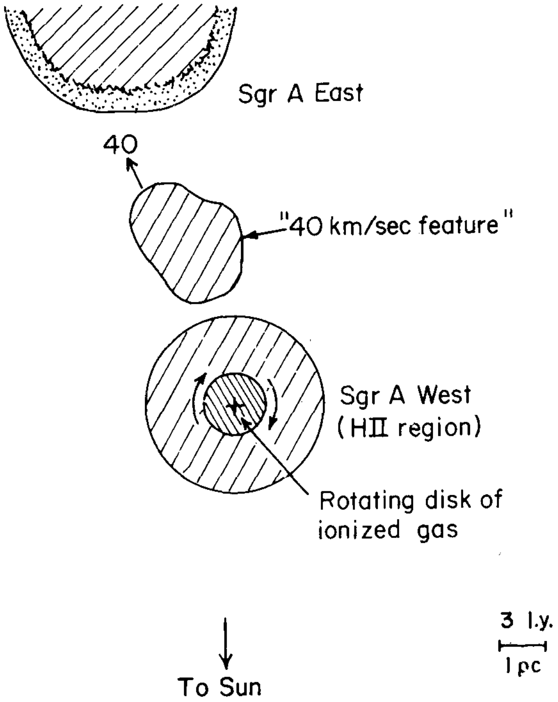


Figure 6.

increase the scale by a further factor ten (Figure 6) if we are to see them well.

Now we are down to a region only a few parsecs across, and we can clearly resolve both Sgr A East and Sgr A West. The former is a bright supernova remnant—the remains of an exploded star; while Sgr A West surrounds the galactic centre itself. Between the two, a giant molecular cloud rushes away from the centre with a velocity of 40 km/s. Although superficially resembling Sgr B2, this '+40 km/s feature' lacks the clouds of brightly glowing hydrogen which would indicate that star formation is in progress. Some astronomers think that this reveals the feature's youth, and they believe that it was ejected from the galactic centre no more than 500,000 years ago.

Sgr A West is another unique object. It is an H II region—not a particularly large one—yet it has a surprisingly smooth structure, quite unlike the chaotic clumpiness of most gas clouds. Perhaps the stars which excite the gas are very evenly distributed. Or—more likely—the whole cloud is lit by *one* single exciting source at the centre. We must go in search of the answer by venturing towards the centre of Sgr A West.

The ionized gas disk

As we near the centre of Sgr A West, we notice that the ionized gas is forming into a thin, rotating disk no more than a couple of parsecs across. Figure 7 shows this region, on a ten-

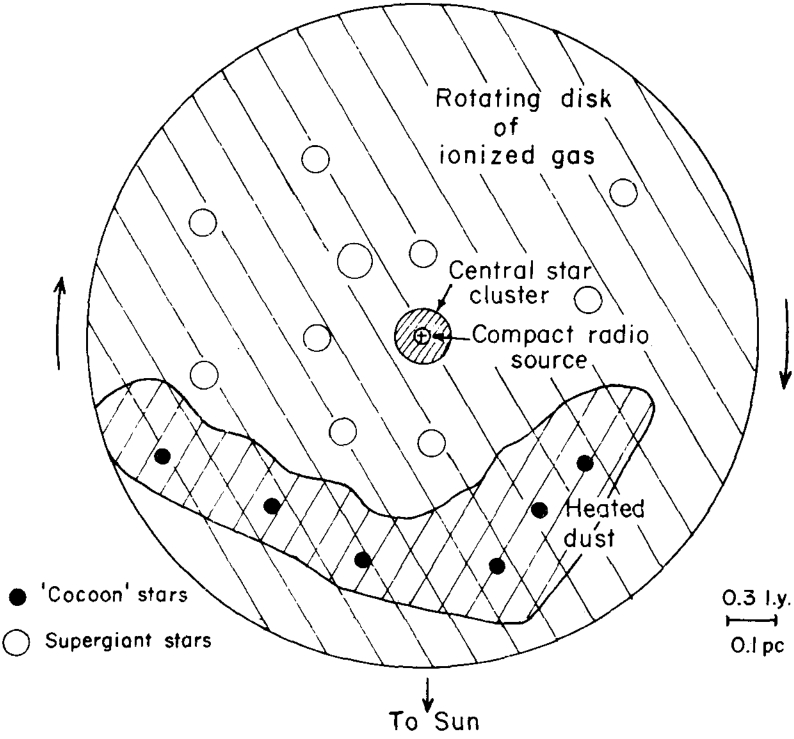


Figure 7.

times increased scale. This ionized disk is actually a thousand times smaller than the first disk (of cool, neutral hydrogen) we encountered around the galactic centre. In fact, it is so small that our Sun and the nearest star, Alpha Centauri, would fit neatly on opposite sides of it!

Up till now, we have been discussing how radio observations have been used to probe the structure of our Galaxy. But now we switch to the shorter infra-red radiation, because, especially in recent years, observations at these wavelengths have played a great part in unravelling the mysteries of the nucleus. In particular, they have proved invaluable in minutely probing the motions of the ionized gas disk. Infra-red astronomers can lock in on a spectral line at 12.8 microns coming from atoms of singly ionized neon (Neon II) in the disk. They believe—albeit tentatively—that the disk is in uniform rotation about the galactic centre. But the widths and asymmetries of the spectral lines within the disk tell us that the gas is involved in considerable streaming motions. As the rotation period at this distance from the galactic centre is so short—only 15,000 years—these gas streams cannot exist as individual entities for very long. To maintain the observed state of turmoil, major eruptions in the nucleus are needed every 10,000 years or so. And although supernovæ could provide the enormous energy required, it is unlikely that stars would explode often enough in this tiny region of space.

What about stars near the galactic centre? The infra-red results indicate that some may actually be forming inside this ionized gas disk. The disk contains considerable quantities of heated dust, important in the early stages of star formation; and there are several sources in the disk which appear to be baby stars, still wrapped in their dusty cocoons. Other point sources are believed to be exceedingly luminous supergiant stars—10,000 to 100,000 times brighter than the Sun.

Although optical astronomers cannot see the stars near the galactic centre, it is possible to map their distribution from the 'heat radiation' they emit in the infra-red. Their space density increases alarmingly as we approach the central star cluster, which is located around the galactic nucleus. Here, the stars are packed together some 100 million times more closely than they are in the neighbourhood of the Sun! What would this mean to the inhabitant of a planet near the galactic centre? His sky would be aglow—day and night—with the light of a thousand million stars. Many of these would appear as bright as the Full Moon in our skies. And his nearest stellar neighbours, instead of being coldly remote, would be a mere four light days away.

Some astronomers have estimated that the mass of the central star cluster is around a million times the mass of the Sun. But the ionized disk needs a mass some five times greater to control its rotation. It is certainly possible that we have underestimated the mass of the central star cluster, or possibly we may not be correct about the dynamics of the ionized disk. But current thinking suggests that the ultra-compact, innermost region of our Galaxy may contain some four million solar masses which is not in the form of stars.

What form could this mass take? Once again, we return to the radio astronomers, for the centre of the ionized disk is marked by a tiny radio source.

The nuclear radio source

Just over a year ago, two radio astronomy groups separated by half the diameter of the world linked up the output from their telescopes. Their aim was to attain the resolution of a radio telescope thousands of miles across, in an attempt to probe the structure of the nuclear source. This technique—known as Very Long Baseline Interferometry, or VLBI—has revealed the smallest features yet discovered at the centre of the Galaxy.

We are now working to such a scale that we can use the Earth's distance from the Sun—the Astronomical Unit (a.u.)—as a unit of measurement. The VLBI results showed the diameter of the central radio source to be 150 a.u.; but some 25 per cent of the power was found to come from an ultra-compact region only 10 a.u. across. This incredibly powerful source would only just be visible in the diagrams if Figure 7 were expanded a thousand times. And it is staggering to consider that—were it in our solar system—this tiny region would fit within the orbit of the planet Jupiter!

Although the output of this central source is several million times weaker than the fantastically powerful nuclei of quasars and radio galaxies (but it does seem to be slightly variable), its emission, volume for volume, is comparable. What can be responsible for this tremendous concentrated energy production? In the absence of observations, we can only speculate.

At present, there is only one mechanism suggested which can produce so much energy in such a small region: the acceleration of charged particles in an accretion disk—the ring of gas spiralling into a black hole. This may sound far-fetched. But current theories of galaxy formation show that a central black hole may form early on in a galaxy's life, following the first rapid infall of material. The black hole may not always be 'active', with an energetic accretion disk. But if there is sufficient gas present in its surrounding accretion disk then the galaxy's nucleus will be able to glow, and there will be a source of energy which can push away clouds of gas at high speeds. When the accretion disk dies away, the galaxy's power is temporarily sapped, and it becomes quiescent; until another infall of gas recreates the accretion disk.

At present our own Galaxy is certainly not active. But there are other spiral galaxies—such as NGC 4258—which show evidence for enormous activity in the past, and which are currently very quiet. And we have already noted that Seyfert galaxies are probably passing through a temporary active phase. If our Galaxy is also spasmodically active, how long ago did it last explode? The expansion of the 3 kpc arm points to an ejection from the nucleus some 12 million years ago, while there must have been a disturbance only a million years in the past to account for the outward-moving molecular clouds. And the persistence of streams of gas in the ionized disk indicates that smaller disturbances occur every 10,000 years or so.

Perhaps these tentative conclusions are not entirely accurate. But they fit the present evidence well, and they are a 'working hypothesis' which can predict future behaviour, and can suggest which observations should be made in the next few years. There are still many mysteries to be unravelled at the heart of our Galaxy, and I feel that the words of leading Russian astrophysicist Josef Shklovsky, written over twenty years ago when the 3 kpc arm was discovered, will ring true for many years to come: 'We have to face the fact that there is some outstanding peculiarity at the galactic centre, whose study will become one of the central problems of astrophysics and cosmology.'

Recent Advances in Astronomy

PATRICK MOORE

Astronomy today is a fast-moving science, and selecting a few 'highlights' for the period between the summer of 1977 and the summer of 1978 is by no means easy. Let us begin, however, near home – in fact, on the Moon. Each Apollo landing team deposited equipment on the lunar surface, and all these ALSEPs or Apollo Lunar Surface Experimental Packages – apart from the first – were still working long after the last men had left the Moon. Unfortunately some of the instruments were starting to deteriorate, and the cost of monitoring all the information sent back was high. NASA therefore took the decision to switch the equipment off, and this was done on 30 September 1977, so that once again the Moon is silent. One has to admit that the most important of the results had already been received and analysed, though lunar enthusiasts will regret that we no longer receive news about the mild ground tremors which affect the Moon.

The Viking landers on Mars are still working, but the life-search experiment has come to an end, and we do not have any proof that living matter exists there. Of course it is too early to be certain, and it must be remembered that we depend entirely upon samples analysed from two sites only: Chryse and Utopia. On the other hand, it is now fair to say that most of the research teams feel that the presence of any life on Mars is improbable. This is a frank disappointment, but in every other way Mars has proved to be even more fascinating than expected. The evidence for past water activity now seems overwhelming, and there is a great deal of H_2O locked up in the polar caps. Moreover, dust-storms seem to be much commoner than had been previously thought.

By contrast, Venus becomes less attractive with every new discovery! As I write these words (18 June 1978) the first of two American Pioneers has been dispatched towards the planet. It was launched on 20 May from Cape Canaveral. The 1280-lb., 8-ft. diameter drum-shaped probe will reach Venus in early December, all being well, and will go into orbit round the planet. The surface features will be mapped by radar, and studies will be made of the atmospheric density and composition, the nature of the clouds, and any trace of a magnetic field. The second Pioneer, due for launching in the near future, will carry four separate vehicles on its back, which will be parachuted down in different regions, though there is to be no attempt at picture-transmission. Full details of the results will be given in the 1980 *Yearbook,* but it is not likely that there will be any need to modify our present knowledge of Venus to any dramatic extent. It is strange now to reflect that in 1962, the time when the first *Yearbook* came out, Venus was still regarded as a more promising potential colony than Mars!

Two Voyagers continue on their way to Saturn, via Jupiter. Jupiter will be by-passed in 1979, and Pioneer 11, which sent back close-range information from Jupiter in 1974, is scheduled to make a pass of Saturn, though whether any pictures will be obtained from it seems rather dubious. Again we will be able to give details in our next issue.

There has been a surge of interest in Uranus, following the detection of the ring-system. Two more 'near miss' occultations have been observed recently, and some new information has come to hand. One phenomenon occurred on 23 December 1977; the other on 10 April 1978. The latter event was studied by E. Persson, using the great reflector at Las Campanas in Chile, and he has concluded that there may be as many as eight rings, one of which is variable in width (narrowest at the closest point to Uranus). However, as Gordon Taylor points out in his article (on p. 177), we cannot hope to obtain really reliable information until the first probes by-pass the planet, which cannot happen for some years yet.

A research programme along roughly the same lines was carried out on 29 May 1978, when the minor planet Pallas occulted a star. Excellent observations were obtained from various points in the United States, again organized by Gordon Taylor, and it is hoped to obtain accurate results for the diameter of Pallas. Up to now the main success has been obtained with the smaller asteroid Hebe, whose diameter is now known to be 121 miles (195 kilometres) with a maximum error of 6 kilometres either way.

No bright comets have been seen during the period under review, but some interesting results have been announced for D'Arrest's periodical comet, which approached us within 25 million kilometres (less than 16 million miles) in 1976. It was studied with the 60-inch reflector in Arizona, and T. Fay and W. Wisniewski have concluded that the nucleus is 2 km (1.24 miles) in diameter, pearshaped, and rotating in a period of 5 hours 10 minutes. D'Arrest's Comet is an old friend; it has been seen regularly ever since its discovery in 1851. The period is 6.7 years. At the 1976 return it was ideally placed, and was just visible with the naked eye.

Activity on the Sun has been building up slowly toward the next maximum, due about 1980, though it is fair to say that large spots have been less frequent than is common at this stage of a cycle. Great attention has been paid to the numbers of neutrinos emitted. Since a neutrino has no charge and no mass, it is not particularly easy to detect, but it has become clear that the Sun is sending out fewer neutrinos than it should theoretically do. A 'neutrino telescope' is a strange instrument, consisting basically of a huge tank of cleaning fluid or some such substance located underground. The Russians have just completed a new instrument of this kind, and have placed it under a site in the Caucasus Mountains. It contains 3200 scintillation chambers and 330 tons of tetrachlorethylene, and is filled with photomultipliers to record each neutrino capture. It will be important to find out whether the results are in agreement with a similar installation in the United States. If it is confirmed that neutrinos really are unexpectedly scarce, solar physicists will have a major problem on their hands.

In the 1978 *Yearbook* mention was made of Eggen's Star, in Sculptor, which was thought to be very close – perhaps even nearer than Proxima Centauri. However, this has proved not to be the case, and Eggen's Star is much more remote than was then believed. On the whole it seems unlikely that there is any star within a radius of 4.2 light-years of us; Proxima will almost certainly retain its title of our nearest stellar neighbour.

Betelgeux, in Orion, is one of the brightest stars in the sky. It is a huge Red Giant, lying at a distance of at least 520 light-years (recent measurements increase this to 620 light-years, though there is bound to be considerable uncertainty). Stars of this type have long been known to be surrounded by extensive shells of gas and dust. Using the 107-in. reflector at the McDonald Observatory, together with photoelectric scanning equipment, D. L. Lambert and A. P. Bernat have shown that Betelgeux is associated with a potassium 'halo' with a diameter of at least 11,000 astronomical units. The density is of course incredibly low, and it is concluded that the outermost potassium atoms were thrown off the star 2,700 years ago. Betelgeux is a variable star; it has a very rough period of around 5 years, and in 1977-8 it was near minimum, though it was still appreciably brighter than Aldebaran in Taurus.

Infra-red astronomy is becoming increasingly important. In November 1977 a 92-inch (2.3 metre) radio telescope was brought into use at Jelm Mountain, in Wyoming. The programme of building the telescope was completed in only 2½ years, which must be something of a record, and the telescope is of course of the most sophisticated type. At the moment it is the largest operational infra-red telescope, though it will soon be surpassed by the British instrument built in Sheffield and due to be set up in Hawaii. The latter telescope has provided an unexpected bonus. Normally, an infra-red telescope does not need to have so accurate a mirror as a visual or photographic telescope, and this means that the mirror can be relatively thin, which cuts the cost considerably. However, the Sheffield tests indicate that the British mirror is so good that it will be quite usable for 'ordinary' work as well as infra-red, and major advances may be expected from it within the next year or two.

Our Galaxy is one of the senior members of the so-called Local Group, which also contains the Andromeda Spiral, the Triangulum Spiral and the two southern Clouds of Magellan, together with more than two dozen dwarf systems. Two relatively newly-discovered members were announced by the Italian astronomer Maffei, and are known as Maffei 1 and Maffei 2. They lie in Cassiopeia, and are so heavily obscured by dust in our Galaxy that they are hard to see at all. They have set astronomers puzzle after puzzle. Maffei 1 is thought to be of the order of 3,000,000 light-years away; it is a giant elliptical system – not the kind of galaxy that would be expected in the Local Group. Maffei 2 has been estimated to be 15,000,000 light-years off, placing it well beyond the Local Group – yet it lies close to Maffei 1 in Cassiopeia, and has about the same velocity through space. It is a spiral, though details are difficult to make out. Is Maffei 2 really a Local Group system, or not? If it is, then the present distance estimate is much too large; if not, then the similarity of motion with Maffei 1 would be a strange coincidence. All of which serves to show that even in the nearest parts of the universe out knowledge is still very incomplete.

Just as this issue of the *Yearbook* was going to press, a most interesting announcement came from the United States Naval Observatory. It was reported that James Christy, studying plates of the planet Pluto taken with the 61-inch reflector, had detected a satellite of the planet, and that confirmation had been obtained from photographs taken with the 158-inch reflector at Cerro Tololo in Chile. The satellite is said to move at a distance of 12,000 miles from Pluto's surface, and to have a revolution period of $6^d\ 9^h\ 17^m$ — the same as the axial rotation period of Pluto itself. The magnitude is 15 to 16 (about 2 magnitudes fainter than the planet) and the separation between Pluto and its satellite cannot exceed 1″ of arc, so that everything depends upon an apparent elongation of Pluto's tiny image. The name 'Charon' has been tentatively suggested (not to be confused with Chiron, the strange object discovered by Kowal and described elsewhere in this *Yearbook*).

If this discovery is confirmed, it will be of the greatest interest. At the moment it must be regarded as tentative only, and more information should have become available by the time that the *Yearbook* appears in print.

PART THREE

Miscellaneous

Some Interesting Telescopic Variable Stars

Star	R.A.		Dec.			*Period,*	
	h	*m*	°		*Mag. range*	*days*	*Remarks*
R. Andromedæ	0	22	+38	18	6.1-14.9	409	
W Andromedæ	2	14	+44	4	6.7-14.5	397	
Theta Apodis	14	00	−76	33	6.4- 8.6	119	Semi-regular.
R Aquilæ	19	4	+ 8	9	5.7-12.0	300	
R Arietis	2	13	+24	50	7.5-13.7	189	
R Aræ	16	35	−56	54	5.9-6.9	4	Algol type.
R Aurigæ	5	13	+53	32	6.7-13.7	459	
R Boötis	14	35	+26	57	6.7-12.8	223	
Eta Carinae	10	43	−59	25	−0.8- 7.9	—	Unique erratic variable.
I Carinæ	09	43	−62	34	3.9-10.0	381	
R Cassiopeiæ	23	56	+51	6	5.5-13.0	431	
T Cassiopeiæ	0	20	+55	31	7.3-12.4	445	
X Centauri	11	46	−41	28	7.0-13.9	315	
T Centauri	13	38	−33	21	5.5- 9.0	91	Semi-regular.
T Cephei	21	9	+68	17	5.4-11.0	390	
R Crucis	12	20	−61	21	6.9- 8.0	5	Cepheid.
Omicron Ceti	2	17	− 3	12	2.0-10.1	331	Mira.
R Coronæ Borealis	15	46	+28	18	5.8-14.8	-	Irregular
W Coronæ Borealis	16	16	+37	55	7.8-14.3	238	
R Cygni	19	35	+50	5	6.5-14.2	426	
U Cygni	20	18	+47	44	6.7-11.4	465	
W Cygni	21	34	+45	9	5.0- 7.6	131	
SS Cygni	21	41	+43	21	8.2-12.1	-	Irregular.
Chi Cygni	19	49	+32	47	3.3-14.2	407	Near Eta.
Beta Doradûs	05	33	−62	31	4.5- 5.7	9	Cepheid.
R Draconis	16	32	+66	52	6.9-13.0	246	
R Geminorum	7	4	+22	47	6.0-14.0	370	
U Geminorum	7	52	+22	8	8.8-14.4	-	Irregular.
R Gruis	21	45	−47	09	7.4-14.9	333	
S Gruis	22	23	−48	41	6.0-15.0	410	
S Herculis	16	50	+15	2	7.0-13.8	307	
U Herculis	16	23	+19	0	7.0-13.4	406	
R Hydræ	13	27	−23	1	4.0-10.0	386	
R Leonis	9	45	+11	40	5.4-10.5	313	Near 18, 19.
X Leonis	9	48	+12	7	12.0-15.1	-	Irregular (U Gem type).
R Leporis	4	57	-14	53	5.9-10.5	432	'Crimson star.'
R Lyncis	6	57	+55	24	7.2-14.0	379	
W Lyræ	18	13	+36	39	7.9-13.0	196	
T Normæ	15	40	−54	50	6.2-13.4	293	
HR Delphini	20	40	+18	58	3.6- ?	-	Nova, 1967.
S Octantis	17	46	−85	48	7.4-14.0	259	
U Orionis	5	53	+20	10	5.3-12.6	372	
Kappa Pavonis	18	51	−67	18	4.0- 5.5	9	Cepheid.
R Pegasi	23	4	+10	16	7.1-13.8	378	
S Persei	2	19	+58	22	7.9-11.1	810	Semi-regular.
R Sculptoris	01	24	−32	48	5.8- 7.7	363	Semi-regular.

Star	R.A.		Dec.			*Period*	
	h	*m*	°	′	*Mag. range*	*days*	*Remarks*
R Phœnicis	23	53	−50	05	7.5–14.4	268	
Zeta Phœnicis	01	06	−55	31	3.6– 4.1	1	Algol type.
R Pictoris	04	44	−49	20	6.7–10.0	171	Semi-regular.
L² Puppis	07	12	−44	33	2.6– 6.0	141	Semi-regular.
Z Puppis	07	30	−20	33	7.2–14.6	510	
T Pyxidis	09	02	−32	11	7.0–14.0	-	Recurrent nova (1920, 1944)
R Scuti	18	45	− 5	46	5.0– 8.4	144	
R Serpentis	15	48	+15	17	5.7–14.4	357	
SU Tauri	5	46	+19	3	9.2–16.0	-	Irregular (R CrB type).
R Ursæ Majoris	10	41	+69	2	6.7–13.4	302	
S Ursæ Majoris	12	42	+61	22	7.4–12.3	226	
T Ursæ Majoris	12	34	+59	46	6.6–13.4	257	
S Virginis	13	30	−6	56	6.3–13.2	380	
R Vulpeculæ	21	2	+23	38	8.1–12.6	137	

Note: Unless otherwise stated, all these variables are of the Mira type.

Some Interesting Double Stars

The pairs listed below are well-known objects, and all the primaries are easily visible with the naked eye, so that right ascensions and declinations are not given. Most can be seen with a 3-inch refractor, and all with a 4-inch under good conditions, while quite a number can be separated with smaller telescopes, and a few (such as Alpha Capricorni) with the naked eye. Yet other pairs, such as Mizar-Alcor in Ursa Major and Theta Tauri in the Hyades, are regarded as too wide to be regarded as bona-fide doubles!

Name	*Magnitudes*	*Separation"*	*Position angle, deg.*	*Remarks*
Gamma Andromedæ	3.0, 5.0	9.8	060	Yellow, blue. B is again double (0".4) but needs a larger telescope.
Zeta Aquarii	4.4, 4.6	2.6	291	Becoming more difficult.
Gamma Arietis	4.2, 4.4	8	000	Very easy.
Theta Aurigæ	2.7, 7.2	3	330	Stiff test for 3 in. OG
Delta Boötis	3.2, 7.4	105	079	Fixed.
Epsilon Boötis	3.0, 6.3	2.8	340	Yellow, blue. Fine pair.
Kappa Boötis	5.1, 7.2	13	237	Easy.
Zeta Cancri	5.6, 6.1	5.6	082	
Iota Cancri	4.4, 6.5	31	307	Easy. Yellow, blue.
Alpha Canum Venat.	3.2, 5.7	20	228	Yellowish, bluish. Easy.
Alpha Capricorni	3.3, 4.2	376	291	Naked-eye pair. Alpha again double.
Eta Cassiopeiæ	3.7, 7.4	11	298	Creamy, bluish. Easy.
Beta Cephei	3.3, 8.0	14	250	
Delta Cephei	var, 7.5	41	192	Very easy.

SOME INTERESTING DOUBLE STARS

Name	*Magnitudes*	*Separation"*	*Position angle, deg.*	*Remarks*
Alpha Centauri	0.0, 1.7			Binary; period 80 years. Very easy.
Xi Cephei	4.7, 6.5	6	270	Reasonably easy.
Gamma Ceti	3.7, 6.2	3	300	Not too easy.
Alpha Circini	3.4, 8.8	15.8	235	PA, slowly decreasing.
Zeta Coronæ Borealis	4.0, 4.9	6.3	304	
Delta Corvi	3.0, 8.5	24	212	
Alpha Crucis	1.6, 2.1	4.7	114	Third star in low-power field.
Gamma Crucis	1.6, 6.7	111	212	Wide optical pair.
Beta Cygni	3.0, 5.3	35	055	Yellow, green. Glorious.
61 Cygni	5.3, 5.9	25	150	
Gamma Delphini	4.0, 5.0	10	265	Yellow, greenish. Easy.
Nu Draconis	4.6, 4.6	62	312	Naked-eye pair.
Alpha Geminorum	2.0, 2.8	2	151	Castor. Becoming easier.
Delta Geminorum	3.2, 8.2	6.5	120	
Alpha Herculis	var, 6.1	4.5	110	Red, green.
Delta Herculis	3.0, 7.5	11	208	Optical double.
Zeta Herculis	3.0, 6.5	1.4	300	Fine, rapid binary.
Gamma Leonis	2.6, 3.8	4.3	121	Binary; period 400 years
Alpha Lyræ	0.0, 10.5	60	180	Vega. Optical; B faint.
Epsilon Lyræ	4.6, 6.3 4.9, 5.2	3 2.3	005 111	Quadruple. Both pairs separable in 3 in. OG
Zeta Lyræ	4.2, 5.5	44	150	Fixed. Easy double.
Beta Orionis	0.1, 6.7	9.5	205	Rigel. Can be split with 3 in.
Iota Orionis	3.2, 7.3	11	140	
Theta Orionis	6.0, 7.0 7.5, 8.0			The famous Trapezium in M.42
Sigma Orionis	4.0, 7.0	11.1 12.9	236 085	Quadruple. D is rather faint in small apertures.
Zeta Orionis	1.9, 5.0	3	160	
Eta Persei	4.0, 8.5	28.5	300	Yellow, bluish.
Beta Phoenicis	4.1, 4.1	1.3	352	Slow binary.
Beta Piscis Austrini	4.4, 7.9	30.4	172	Optical pair. Fixed.
Alpha Piscium	4.3, 5.3	1.9	291	
Kappa Puppis	4.5, 4.6	9.8	318	Again double.
Alpha Scorpii	0.9, 6.8	3	275	Antares, Red. green.
Nu Scorpii	4.2, 6.5	42	336	
Theta Serpentis	4.1, 4.1	23	103	Very easy.
Alpha Tauri	0.8, 11.2	130	032	Aldebaran. Wide, but B is very faint in small telescopes.
Beta Tucanæ	4.5, 4.5	27.1	170	Both components again double.
Zeta Ursæ Majoris	2.3, 4.2	14.5	150	Mizar. Very easy. Naked eye pair with Alcor.
Alpha Ursæ Minoris	2.0, 9.0	18.3	217	Polaris. Can be seen with 3 in.
Gamma Virginis	3.6, 3.7	4.8	305	Binary; period 180 yrs. Closing.
Theta Virginis	4.0, 9.0	7	340	Not too easy.
Gamma Volantis	3.9, 5.8	13.8	299	Very slow binary.

Some Interesting Nebulae and Clusters

Object	R.A.		Dec.		*Remarks*
	h	*m*	°		
M.31 Andromedæ	00	40.7	+41	05	Great Galaxy, visible to naked eye.
H.VIII 78 Cassiopeiæ	00	41.3	+61	36	Fine cluster, between Gamma and Kappa Cassiopeiæ.
M.33 Trianguli	01	31.8	+30	28	Spiral. Difficult with small apertures.
H.VI 33–4 Persei	02	18.3	+56	59	Double cluster; Sword-handle.
Δ142 Doradûs	05	39.1	−69	09	Looped nebula round 30 Doradûs. Naked-eye. In Large Cloud of Magellan.
M.1 Tauri	05	32.3	+22	00	Crab Nebula, near Zeta Tauri.
M.42 Orionis	05	33.4	−05	24	Great Nebula. Contains the famous Trapezium, Theta Orionis.
M.35 Geminorum	06	06.5	+24	21	Open cluster near Eta Geminorum.
H.VII 2 Monocerotis	06	30.7	+04	53	Open cluster, just visible to naked eye.
M.41 Canis Majoris	06	45.5	−20	42	Open cluster, just visible to naked eye.
M.47 Puppis	07	34.3	−14	22	Mag. 5,2. Loose cluster.
H.IV 64 Puppis	07	39.6	−18	05	Bright planetary in rich neighbourhood.
M.46 Puppis	07	39.5	−14	42	Open cluster.
M.44 Cancri	08	38	+20	07	Præsepe. Open cluster near Delta Cancri. Visible to naked eye.
M.97 Ursæ Majoris	11	12.6	+55	13	Owl Nebula, diameter 3′. Planetary.
Kappa Crucis	12	50.7	−60	05	"Jewel Box"; open cluster, with stars of contrasting colours.
M.3 Can. Ven.	13	40.6	+28	34	Bright globular.
Omega Centauri	13	23.7	−47	03	Finest of all globulars. Easy with naked eye.
M.80 Scorpii	16	14.9	−22	53	Globular, between Antares and Beta Scorpionis.
M.4 Scorpii	16	21.5	−26	26	Open cluster close to Antares.
M.13 Herculis	16	40	+36	31	Globular. Just visible to naked eye.
M.92 Herculis	17	16.1	+43	11	Globular. Between Iota and Eta Herculis.
M.6 Scorpii	17	36.8	−32	11	Open cluster; naked-eye.
M.7 Scorpii	17	50.6	−34	48	Very bright open cluster; naked eye.
M.23 Sagittarii	17	54.8	−19	01	Open cluster nearly 50′ in diameter.
H.IV 37 Draconis	17	58.6	+66	38	Bright Planetary.
M.8 Sagittarii	18	01.4	−24	23	Lagoon Nebula. Gaseous. Just visible with naked eye.
NGC 6572 Ophiuchi	18	10.9	+06	50	Bright planetary, between Beta Ophiuchi and Zeta Aquilæ.
M.17 Sagittarii	18	18.8	−16	12	Omega Nebula. Gaseous. Large and bright.
M.11 Scuti	18	49.0	−06	19	Wild Duck. Bright open cluster.
M.57 Lyræ	18	52.6	+32	59	Ring Nebula. Brightest of planetaries.
M.27 Vulpeculæ	19	58.1	+22	37	Dumb-bell Nebula, near Gamma Sagittæ.
H.IV 1 Aquarii	21	02.1	−11	31	Bright planetary near Nu Aquarii.
M.15 Pegasi	21	28.3	+12	01	Bright globular, near Epsilon Pegasi.
M.39 Cygni	21	31.0	+48	17	Open cluster between Deneb and Alpha Lacertæ. Well seen with low powers.

Some Recent Books

Mars and its Satellites, by Jürgen Blunck. Exposition Press, Hicksville, New York, 1977. Not a general account of Mars, but a detailed commentary upon Martian nomenclature, with many interesting historical notes.

Planetary Satellites, edited by Joseph A. Burns. University of Arizona Press, Tucson, 1977. A technical survey of the natural satellites of the planets, aimed at the serious researcher.

The Historical Supernovæ, by David H. Clark and F. Richard Stephenson. Pergamon Press, Oxford, 1977. An exhaustive study of the supernovæ which have been recorded in our Galaxy.

The Collapsing Universe, by Isaac Asimov. Hutchinson, London, 1977. Sub-titled 'The Story of Black Holes'. A popular book, written in the author's usual entertaining and impeccable style.

Astronomy: An Introduction, by Jacqueline Milton, Faber & Faber, London 1978. Excellent, concise outline of modern astronomy by a Cambridge astrophysicist.

Guide to Comets, by Patrick Moore. Lutterworth Press, Guildford, 1977. A popular account of modern cometary astronomy.

The Cambridge Encyclopædia of Astronomy, edited by Simon Mitton. Cambridge University Press, 1977. An overall survey of modern astronomy, written in semi-popular style—expensive, but well worth the price charged for it!

Make Your Own Telescope from everyday materials, by Reg Spry, Sidgwick & Jackson, London, 1978. An illustrated description of how to make a telescope cheaply excluding the optics. The author is a Council Member of the B.A.A.

Our Contributors

DR RON MADDISON is well known to readers of the *Yearbook*, and to the general public because of his television broadcasts. He is a graduate of Keele University, where he is now Professor of Physics and in charge of the University Observatory. In addition to his technical researches, he is keenly interested in the popularization of astronomy, and gives many lectures.

PETER J. GARBETT is a young member of the British Astronomical Association. He has erected a private observatory at his home in Barton-le-Clay in Bedfordshire, and is particularly interested in studies of the Moon.

PROFESSOR CHARLES T. KOWAL attended the University of Southern California, 1957-61, and received his B.A. degree. He was Research Assistant at the Hale Observatories, 1961-63; CalTech, 1963-5, 1966-75; University of Hawaii, 1965-6; Associate Scientist at CalTech from 1976 to the present time. He has discovered 80 supernovæ, 5 Apollo-type asteroids, one comet, one satellite of Jupiter (Leda) and a possible second, and the new object Chiron. He has also recovered several lost comets and asteroids. He is the author of about two dozen technical papers and several popular articles. He lives in La Crescenta, California, with his wife and 8-year-old daughter.

DR GARRY E. HUNT, formerly of the Meteorological Office (Bracknell) and now of University College, London, is one of the world's leading experts in planetary research, and is closely concerned with current space-probe projects, so that he makes frequent visits to American centres. In addition to his many technical contributions he is also well known for his television broadcasts and popular lectures.

GORDON E. TAYLOR, of the Nautical Almanac Office, Royal Greenwich Observatory (Herstmonceux) is essentially a mathematician who has developed various new methods of research—including the measurement of the diameters of small or remote planetary bodies by means of occultation techniques. He is a Past President of the British Astronomical Association.

CICELY M. BOTLEY has a world reputation as an astronomical historian, specializing in records of ancient comets, auroræ and eclipses. She is a long-standing member of the British Astronomical Association, and has presented many papers; she is the author of a book, *The Polar Aurora,* and is also a meteorologist.

Dr DAVID A. ALLEN (one of our most regular and welcome contributors!) took his B.A. at Cambridge University in 1967, and his PhD. in 1971. After some years at the Royal Greenwich Observatory, he is now continuing his research in Australia. His recent work has concentrated upon infrared astronomy, for which he has used some of the world's most powerful telescopes, including the Palomar 200-inch.

DR F. RICHARD STEPHENSON, of the University of Newcastle-on-Tyne, is a specialist in scientific history, and has undertaken much original research, notably in connection with Chinese records.

HEATHER COUPER is Lecturer at the Greenwich Planetarium, National Maritime Museum. A graduate of the University of Leicester, she did research on galaxies at Oxford University before branching out into popular astronomy. As well as lecturing and writing extensively, she serves on the Councils of both the British Astronomical Association and the Junior Astronomical Society.

MICHAEL BODE is a graduate of Keele University. He is currently completing his PhD thesis, and has chosen lunar transient phenomena as his subject; during the course of his studies he has undertaken considerable original research.

Astronomical Societies in Great Britain

The advantages of joining an astronomical society are obvious enough. Full information about national and local Societies was given in the 1966 *Yearbook;* a condensed list, suitably brought up to date, is given below.

Editor's Note. It has been decided to omit subscriptions as they were found to be continually out of date.)

British Astronomical Association
Secretary: J. L. White, Burlington House, Piccadilly, London, W.1.
Meetings: Burlington House, Piccadilly. Last Wed. each month (Oct.-June).

Irish Astronomical Association
Secretary: D. Beesley, The Planetarium, Armagh.
Meetings: Belfast, fortnightly. Armagh, monthly.

Junior Astronomical Society
Secretary: 58 Vaughan Gardens, Ilford, Essex.
Meetings: Alliance Hall, Palmer Street, W.C.1. Last Saturday Jan., April, July, Oct 2.30 p.m.

Aberdeen and District Astronomical Society
Secretary: W. P. Cooper, 14 Abbotshall Gardens, Cults, Aberdeen.
Meetings: Robert-Gordon's Institute of Technology, St Andrew Street, Aberdeen.

Altrincham and District Astronomical Society
Secretary: Colin Henshaw, 10 Delamere Road, Gatley, Cheadle, Cheshire.
Meetings: Park Road Library, Timperley. 1st Friday of each month, 7.30 p.m.

Aylesbury Astronomical Society
Secretary: N. Neale, 9 Elm Close, Butler's Cross, Aylesbury.
Meetings: As arranged.

Bassettlaw Astronomical Society
Secretary: S. Archer, 48 Raines Avenue, Worksop, Notts.
Meetings: Teachers' Centre Hall, Worksop (Tuesday fortnightly) and Denman Library, Retford (1st Monday each month).

Birmingham Astronomical Society
Secretary: A. R. J. Foulger, 14 Plants Brook Road, Walmley, Sutton Coldfield.
Meetings: Birmingham and Midland Institute. Monthly.

Border Astronomical Society
Secretary: David Pettit, 14 Shap Grove, Carlisle, Cumbria.
Meetings: Morton Community Centre, Wigton Road, Carlisle. Monthly by arrangement.

Bradford Astronomical Society
Secretary: B. Jones, 28 High House Avenue, Bolton, Bradford, W. Yorks.
Meetings:

Bridgwater Astronomical Society
Secretary: W. L. Buckland, The Bridgwater College, Bridgwater, Somerset.
Meetings: Room 4, Blake Street Centre, Bridgwater College. 3rd Wednesday in each month.

Brighton Astronomical Society
Secretary: Mrs B. C. Smith, Flat 2, 23 Albany Villas, Hove, Sussex, BN3 2RS.
Meetings: Preston Tennis Club, Preston Drive, Brighton. Weekly, Tuesdays.

Bristol Astronomical Society
Secretary: G. H. Woodman, 34 Butterfield Close, Bristol BS10 5AZ.
Meetings: Royal Fort (Rm G44), Bristol University. Last Friday each month, Sept.-May.

Caithness and Dounreay Astronomical Society
Secretary: Miss M. J. A. Clark, Room 31, Ormlie Lodge, Thurso, Scotland.
Meetings: Fortnightly.
Camberley (Surrey) Astronomical Society
Secretary: B. A. Roberts, 45 Ferndale Road, Church Crookham, Aldershot, Hants.
Meetings: (Room B23, Yateley Centre School, School Lane, Yateley, Camberley, Surrey.) 2nd Wednesday each month, 7.45 p.m.
Cambridge Astronomical Society
Secretary: C. A. Cornwell, 53 The Westering, Cambridge.
Meetings: The Village College, Comberton, Cambridge. 2nd Mon. each month, 8 p.m.
Cardiff Astronomical Society
Secretary: D. W. S. Powell, 1 Tal-y-Bont Road, Ely, Cardiff.
Meeting Place: Penylan Observatory, Cyncoed Road, Penylan, Cardiff. Alternate Thursdays, 8 p.m.
Chelmsford and District Astronomical Society
Secretary: Miss C. C. Puddick, 6 Walpole Walk, Rayleigh, Essex.
Meetings: 7.45 p.m. Sandon House School, Sandon Near Chelmsford. 2nd and last Monday of Month.
Chelmsley Astronomical Society
Secretary: Miss D. Calvert, 193 Shard End Crescent, Shard End, Birmingham.
Meetings: Chelmsley Wood Library. Last Thursday in month.
Chester Astronomical Society
Secretary: A. Kemp, 58 Daleside, Upton, Chester, CH2 1EP.
Meetings: St Andrews House, Newgate Street, Chester. Monthly.
Chester Society of Natural Science, Literature and Art
Secretary: Paul Braid, 'White Wing', 38 Bryn Avenue, Old Colwyn, Colwyn Bay, Clwyd.
Meetings: Grosvenor Museum, Chester. Fortnightly.
Chesterfield Astronomical Society
Secretary: Mrs R. C. Naylor, Hilltop Cottage, Gallery Lane, Holymoorside. Chesterfield.
Meetings: Barnett Observatory, Newbold. Each Friday.
Clackmannanshire Astronomical Society
Secretary: J. Cluckie, 9 Deer Park, Sauchie, Alloa.
Meetings: St Mary's School, Alloa. Monthly, 3rd Friday, Sept.-May.
Clacton & District Astronomical Association
Secretary: C. L. Haskell, 105 London Road, Clacton-on-Sea, Essex.
Cleethorpes & District Astronomical Society
Secretary: P. H. Rea, 236 Humberston Avenue, Humberston, Grimsby, South Humberside.
Meetings: Beacon Hill Observatory, Cleethorpes. 1st Wednesday each month.
Clwyd Astronomical Society
Secretary: K. J. Payne, 2 Veto Villas, Rhyl Road, Denbigh, Clwyd.
Meetings: Details on request.
Colchester Amateur Astronomers
Secretary: F. Kelly, 'Middleton', Church Road, Elmstead Market, Colchester, Essex.
Meetings: William Loveless Hall, High Street, Wivenhoe. Friday evenings. Fortnightly.
Coventry & Warwicks Astronomical Society
Secretary: 238 Sovereign Road, Earlsdon, Coventry, Warwicks.
Meetings: Coventry Technical College. Fortnightly.
Crawley Astronomical Society
Secretary: G. Cowley, 67 Climpixy Road, Ifield, Crawley, Sussex.
Meetings: Crawley College of Further Education. Monthly Oct.-June.
Crayford Manor House Astronomical Society
Secretary: R. H. Chambers, Manor House Centre, Crayford, Kent.
Meetings: Manor House Centre, Crayford. Monthly during term-time.
Croydon Astronomical Society
Secretary: K. Brackerborough, 342 Lower Addiscombe Road, Croydon.
Meetings: Normanton Park Hotel, 34 Normanton Road, South Croydon. Alternate Fridays, 7.45 p.m.
Dartington Astronomical Society
Secretary: Mrs Iris Allison, 'Wayfaring', Cott Lane, Dartington, Totnes, Devon.
Meetings: Meeting Room, Shinners Bridge Centre, Dartington. 3rd Wed. each month at 8 p.m. Observation all other Wed. evenings (weather permitting) on Foxhole clock tower.

ASTRONOMICAL SOCIETIES IN GREAT BRITAIN

Derby & District Astronomical Society
Secretary: Jane D. Kirk, 7 Cromwell Avenue, Findern, Derby.
Meetings: At home of Secretary. First and third Friday each month, 7.30 p.m.

Dundee Astronomical Society
Secretary: K. Kennedy, 80 Torridon Road, Broughty Ferry, Dundee.
Meetings: Mills Observatory, Dundee. Fortnightly in the winter.

Eastbourne Astronomical Society
Secretary: R. W. Cripps, 10 Framfield Way, Eastbourne.
Meetings: Girl Guide HQ, Hartfield Road, Eastbourne. Last Saturday each month.

East Lancashire Astronomical Society
Secretary: D. Chadwick, 16 Worston Lane, Great Harwood, Blackburn, BB6 7TH.
Meetings: As arranged. Monthly.

Astronomical Society of Edinburgh
Secretary: N. G. Matthew, 126 W. Saville Terrace, Edinburgh 9, Scotland.
Meetings: Calton Hill Observatory, Edinburgh. Monthly.

Ewell Astronomical Society
Secretary: Ron W. Johnson, 19 Elm Way, Ewell, Surrey.
Meetings: Minor Hall, Bourne Hall, Ewell. 1st Friday of each month.

Farnham Astronomical Society
Secretary: John Fannon, 10 Willow Way, Hale, Farnham, Surrey.
Meetings: Adult Education Centre, 32 South Street, Farnham. 2nd Monday each month, 7.45 p.m.

Federation of Astronomical Societies
Secretary: G. Pearce, 1 Valletort Cottages, Millbridge, Plymouth, P11 5PU.

Fellowship of Junior Astronomers, Edinburgh
Secretary: Miss Edith McLean, 58 Ogilvie Terrace, Edinburgh 11, Scotland.
Meetings: Calton Hill Observatory, Edinburgh. 3rd Fri. each month, Sept-June.

Furness Astronomical Society
Secretary: R. Alldridge, 56 Hartington Street, Barrow-in-Furness, Cumbria.
Meetings: Barrow Library. 1st Saturday in month, 2 p.m.

Fylde Astronomical Society
Secretary: 28 Belvedere Road, Thornton, Lancs.
Meetings: Stanley Hall, Rossendale Ave. South. 1st Wed. each month.

Astronomical Society of Glasgow
Secretary: P. C. Benson, 2 Mingamy St, Glasgow, G20 8NT.
Meetings: University of Strathclyde, George St, Glasgow. 3rd Thursday each month, Sept.-April.

Great Yarmouth Astronomical Society
Secretary: M. Poxon, 10 Tyrrels Road, Great Yarmouth, Norfolk.
Meetings: Public Library. Alternate Fridays.

Guildford Astronomical Society
Secretary: Mrs D. E. Clapson, 12 Durham Close, Guildford.
Meetings: Corona Restaurant, High Street, Guildford. 1st Tue. each month, 7.45 p.m.

Gwynedd Astronomical Society
Secretary: E. Parry, 2 Rhes Groes, Sling, Bangor, Gwynedd.
Meetings: Physics Lecture Room, Bangor University. 1st Thurs. each month, 7.30 p.m.

Astronomical Society of Haringey
Secretary: W. T. Baker, 58 Stirling Road, Wood Green, London, N.22.
Meetings: 673 Lordship Lane, Wood Green, London, N.22. 3rd Thurs. each month, 7.30 p.m.

The Hampshire Astronomical Group
Secretary: S. W. Hackman, 52 Denbigh Drive, Fareham, Hampshire.
Meetings: The Group Observatory.

Harlow Astronomical Group
Secretary: R. Marsh, 9 Charters Cross, Harlow, Essex.
Meetings: 62 Priory Court, Harlow. Tuesdays, fortnightly, 7.30 p.m.

The Herschel Astronomical Society
Secretary: C. D. Chacksfield, 3 Wavendene Avenue, Thorpe Lea, Egham, Surrey, TW20 8JX.
Meetings: Fortnightly at members' homes.

Hull and East Riding Astronomical Society
Secretary: J. I. Booth, 3 Lyngarth Av., Cottingham, North Humberside.
Meetings: College of Higher Education, Queen's Gardens, Hull. Third Friday each month, Oct.-April.

Isle of Wight Astronomical Society
Secretary: J. W. Feakins, 1 Hilltop Cottages, High Street, Freshwater, Isle of Wight.
Meetings: Unitarian Church Hall, Newport, Isle of Wight. Monthly.

King's Lynn Amateur Astronomical Association
Secretary: P. Twynman, 17 Poplar Avenue, R.A.F. Marham, Kings' Lynn.
Meetings: As arranged.

Lancaster University Astronomical Society
Secretary: G. Day, Lunar and Planetary Unit, University of Lancaster.
Meetings: As arranged.

Leeds Astronomical Society
Secretary: M. D. Taylor, 17 Cross Lane, Wakefield, West Yorks.
Meetings: Leeds City Museum/Library. 2nd Wed. each month.

Leicester Astronomical Society
Secretary: Mrs. N. Tunnicliffe, 69 Greenhill Road, Leicester.
Meetings: Leicester Museum and Art Gallery. Monthly.

Lincoln Astronomical Society
Secretary: Robert D. Christy, 41 Meadow Lake Crescent, Birchwood, Lincoln.
Meetings: The Lecture Hall, off Westcliffe Street, Lincoln. First Tues. each month.

Liverpool Astronomical Society
Secretary: D. Bradburne, Simms Cross School House, Mitton Road, Widnes.
Meetings: City Museum, Liverpool. Monthly.

Livingston Astronomical Society
Secretary: 50 Dawson Avenue, Howden, Livingston, West Lothian.
Meetings: Almond Room, Howden House, Howden. Sundays, 7.30 p.m.

Loughton Astronomical Society
Secretary: S. Smith, 6 Baldock Road, Theydon Bois, Epping, Essex.
Meetings: Loughton Hall, Rectory Lane, Loughton, Essex. Thurs., 8 p.m.

Luton Astronomical Society
Secretary: S. J. Anderson, 20 Bloomfield Avenue, Luton.
Meetings: Last Friday each month.

Lytham St. Annes Astronomical Association
Secretary: K. J. Porter, 141 Blackpool Road, Ansdell, Lytham St. Annes, Lancs.
Meetings: College of Further Education, Clifton Drive S., Lytham St. Annes. 2nd Wed. monthly Oct.-June.

Maidenhead Astronomical Society
Secretary: Mr C. Wise, 592 Bath Road, Taplow, Maidenhead, Berks.
Meetings: Maidenhead Grammar School. Every 2nd Thursday. Sept.-June.

Maidenhead Astronomy Group
Secretary: S. A. H. Roper, 129 Fane Way, Maidenhead, Berkshire.
Meetings: Maidenhead Grammar School. Once every 3 weeks.

Manchester Astronomical Society
Secretary: J. H. Davidson, Godlee Observatory, U.M.I.S.T., Sackville Street, Manchester 1.
Meetings: At the Observatory, Thursdays, 7.30-9 p.m.

Mansfield and Sutton Astronomical Society
Secretary: G. Shepherd, 5 Priory Street, Old Lenton, Nottingham, NG7 2NX.
Meetings: The Library, Sutton Centre Complex, High Pavement, Sutton-in-Ashfield, Notts. Third or last Monday in the month.

Mid-Kent Astronomical Society.
Secretary: Mrs. C. Sanders, 80 Thornham Road, Gillingham, Kent, ME8 6RF.

Mid-Sussex Astronomical Society
Secretary: Dr L. K. Brundle, 63 Pasture Hill Road, Haywards Heath, Sussex.
Meetings: Haywards Heath School, Harlands Road. Wednesdays, 7.30 p.m.

Milton Keynes Astronomical Society
Secretary: Paul D. Keen, 26 Betty's Close, Newton Longville, Milton Keynes, MK17 0AN.
Meetings: Alternate Tuesdays.

Newcastle-on-Tyne Astronomical Society
Secretary: D. S. Brown, c/o Sir Howard Grubb Parsons & Co. Ltd., Walkergate, Newcastle-on-Tyne, NE6 2YB.
Meetings: Botany Lecture Theatre, Newcastle University. Monthly, Sept.-April.

Newtonian Observatory Astronomical Society
Secretary: Miss P. E. Randle, 62 Northcott Road, Worthing, Sussex.
Meetings: Adult Education Centre, Union Place, Worthing. 1st Wed. each month except Aug. 7.30. p.m.

North Devon Astronomical Society
Secretary: R. W. Rose, Ararat, 18 The Shields, Ilfracombe, North Devon.
Meetings: Details to be announced later.

North Dorset Astronomical Society
Secretary: J. E. M. Coward, The Pharmacy, Stalbridge, Dorset.
Meetings: Charterhay, Stourton, Caundle, Dorset. 2nd Wed. each month.

North Staffordshire Astronomical Society
Secretary: E. S. Hewitt, 24 Weldon Avenue, Weston Coyney, Stoke-on-Trent.
Meetings: 1st Wed. of each month at Cartwright House, Broad Street, Hanley. No sub. fixed yet.

North Western Association of Variable Star Observers
Secretary: Jeremy Bullivant, 2 Beaminster Road, Heaton Mersey, Stockport, Cheshire SK4 3HT.
Meetings: Four annually.

North Wilts/South Glos Astronomical Group
Secretary: Simon D. Barnes, 'Kelston', Gloucester Road, Malmesbury, Wilts.
Meetings: To be announced.

Norwich Astronomical Society
Secretary: Rev. Cyril D. Blount, The Manse, Back Lane, Wymondham, Norwich.
Meetings: Norwich Observatory, Colney Lane, Cringleford, Norwich. Every Tues. and Sat. Public meetings 3rd Sat. at Spinney Community Centre.

Nottingham Astronomical Society
Secretary: C. Swift, 18 Naseby Close, Heathfield, Nottingham.
Meetings: Monthly.

Orwell Astronomical Society (Ipswich)
Secretary: M. Hadden, 33 Crofton Road, Ipswich, Suffolk.
Meetings: Orwell Park School, Nacton, Ipswich. Weekly.

Oxshott Astronomical Group
Secretary: E. H. Noon, Norman Cottage, Pond Piece, Sheath Lane, Oxshott, Surrey.
Meetings: Oxshott Village Centre. 1st Wed. each month Sept.-May.

Paisley Astronomical Society
Secretary: Mrs J. Holms, 14 Cheviot Avenue, Barrhead, Glasgow.
Meetings: Coats Observatory, 49 Oakshaw Street, Paisley. Monthly.

Peterborough Astronomical Society
Secretary: E. Pitchford, 24 Cissbury Ring, Werrington, Peterborough.
Meetings: Peterborough Technical College. 2nd Tues., 3rd Thur. each month.

Phoenix Astronomical Society
Secretary: B. Jones, 38 Myers Avenue, Bolton, Bradford 2, Yorks.
Meetings: Phoenix Park Sports Club, off Dick Lane, Thornbury, Bradford 3.

Plymouth Astronomical Society
Secretary: G. S. Pearce, 1 Valletort Cotts, Millbridge, Plymouth.
Meetings: Y.W.C.A., Lockyer Street, Plymouth. Monthly.

Portsmouth Astronomical Society
Secretary: G. B. Bryant, 81 Ringwood Road, Southsea.
Meetings: Monday. Fortnightly.

Preston & District Astronomical Society
Secretary: C. Lynch, 35 Bispham Road, Carleton, Poulton-le-Fylde, Lancs.
Meetings: Chamber of Commerce, 49a Fishergate, Preston. 3rd Mon. each month. Sept.-May.

Rayleigh Centre Amateur Astronomical Society
Secretary: Bernard R. Soley, 136 The Chase, Rayleigh, Essex.
Meetings: Fitzwimarc School, Hockley Road, Rayleigh. Every Wed., 8 p.m.

Reading Astronomical Society
Secretary: J. Wrigley, 30 Amherst Road, Reading.
Meetings: Anderson Baptist Church Hall, Reading. Monthly.

Salford Astronomical Society
Secretary: J. A. Handford, 45 Burnside Avenue, Salford 6, Lancs.
Meetings: The Observatory, Chaseley Road, Salford.

Salisbury Plain Astronomical Society
Secretary: R. J. D. Nias, St George's Cottage, Orcheston, Salisbury, Wilts.
Meetings: St George's Rectory, Orcheston. Quarterly.

Scarborough & District Astronomical Society
Secretary: M. D. Wilson, 19 Ryefield Close, Eastfield, Scarborough, N. Yorks YO11
Meetings: North Riding College of Education, Filey Road, Wednesdays, September-June, 7.30-9 p.m.

Sheffield Astronomical Society
Secretary: Mrs Nora Betts, 35 Upper Albert Road, Sheffield.
Meetings: City Museum, Weston Bank. Third Friday each month, Sept.-May inclusive.

Solent Amateur Astronomers
Secretary: R. W. Arbour, 14 Orchard Avenue, Bishopstoke, Eastleigh, Hants.
Meetings: Room 33, Library Block, Southampton University. 3rd Thur. each month, 7.30 p.m.

Southampton Astronomical Society
Secretary: J. G. Thompson, 4 Heathfield, Dibden Purlieu, Southampton.
Meetings: 2nd Thur. each month Unigate Conference Room, Southampton; 4th Thur. each month Room 33, University of Southampton.

South Downs Astronomical Society
Secretary: Mrs Buss, 32 Birdham Close, Stroud Green, Bognor Regis.
Meetings: Last Friday in each month.

South-East Essex Astronomical Society
Secretary: P. A. Laycock, 42 First Avenue, Westcliff-on-Sea, Essex SS0 8HR.
Meetings: Lecture Theatre, Central Library, Victoria Avenue, Southend-on-Sea. Generally 1st Thurs. in month, Sept.-May.

South-East Kent Astronomical Society
Secretary: P. Andrew, 30 Reach Close, St Margaret's Bay, nr Dover.
Meetings: Monthly.

South Lincolnshire Astronomical & Geophysical Society
Secretary: F. F. Bermingham, 19 Field Close, Gosberton, Spalding, Lincs.
Meetings: South Holland Centre, Spalding. 1st Monday each month, 7.30 p.m.

Southport, Ormskirk and District Astronomical Society
Secretary: J. T. Harrison, 92 Cottage Lane, Ormskirk, Lancs L39 3NJ.
Meetings: Saturday evenings, monthly as arranged.

South Shields Astronomical Society
Secretary: H. Haysham, Marine and Technical College, St George's Ave., South Shields, Co. Durham.
Meetings: Marine and Technical College. Each Thurs., 7.30 p.m.

South West Herts Astronomical Society
Secretary: G. J. B. Phillips, 32 Riverford Close, Harpenden, Herts.
Meetings: Royal Masonic School for Girls, Rickmansworth. Last Fri. each month, Sept.-May.

Stoke-on-Trent Astronomical Society
Secretary: M. Pace, Sundale, Dunnocksfold Road, Alsager, Stoke.
Meetings: Cartwright House, Broad Street, Hanley. Monthly.

Swansea Astronomical Society
Secretary: C. Morris, 14 Bath Villas, Morriston, Swansea SA6 7AN.
Meetings: As arranged.

Thames Valley Astronomical Group
Secretary: K. J. Pallet, 82a Tennyson Street, South Lambeth, London, SW8 3TH.
Meetings: Irregular.

Thanet Amateur Astronomical Society
Secretary: P. F. Jordan, 85 Crescent Road, Ramsgate.
Meetings: Hilderstone House, Broadstairs Kent. Monthly.

Torbay Astronomical Society
Secretary: Miss A. Longman, 4 Heath Rise, Brixham, Devon.
Meetings: Quay Tor Hotel, Scarborough Road, Torquay. Monthly.

Waltham Forest & District Junior Astronomy Club
Secretary: B. Crawford, 24 Fulbourne Road, Walthamstow, London E.17.
Meetings: 24 Fulbourne Road, Walthamstow, London E.17. Fortnightly (Mondays).

Warrington Astronomical Society
Secretary: B. P. Rees, 2 Dale Avenue, Appleton, Warrington.
Meetings: Central Library, Museum Street, Warrington, Lancs. Monthly, Sept.-May.

Warwickshire Astronomical Society
Secretary: R. D. Wood, 20 Humber Road, Coventry, Warwickshire.
Meetings: 20 Humber Road, Coventry. Each Tuesday.

Webb Society
Secretary: E. Moore, 7 Elvendon Road, Palmers Green, London, N.13.
Meetings: As arranged.

Wessex Astronomical Group
Secretary: Mrs J. Broadbank, 624 Ringwood Road, Parkstone, Poole, Dorset.
Meetings: Science Block B, Lower Annex, Poole Technical College.

West of London Astronomical Society
Secretary: R. A. Hedley, 96 Warden Avenue, Rayners Lane, Harrow, Middlesex, HA2 9LW.
Meetings: Monthly, alternately at Hillingdon and North Harrow. Second Monday of the month, except August.

West Yorkshire Astronomical Society
Secretary: J. A. Roberts, 76 Katrina Grove, Purston, Pontefract, Yorks, WF7 5LW.
Meetings: The Barn, 4 The Butts, Back Northgate, Pontefract. Every Tues., 7 p.m.

Widnes Astronomical Society
Secretary: Miss A. Williams, 21 Deansway, Ditton, Widnes.
Meetings: To be arranged.

Wolverhampton Astronomical Society
Secretary: M. Astley, Garwick, 8 Holme Mill, Fordhouses, Wolverhampton.
Meetings: Polytechnic, Wulfruna Street, Wolverhampton. Alternate Mon., Sept.-April.

Wyvern Astronomical Society
Secretary: A. F. Edwards, 2 Howcroft, Churchdown, Gloucester.
Meetings: Clubhouse, Churcham. Last Friday of each month except Aug.

York Astronomical Society
Secretary: Mrs J. Acton, 1 Low Catton Road, Stamford Bridge, York.
Meetings: York Railway Institute. Fortnightly, Fridays.

Zenith Astronomical Society
Secretary: A. Harvey, 10 Meadow Close, Reedby, nr Burnley.
Meetings: 54 Cromwell Street, Burnley. 1st Wednesday in each month.

It is possible that this list of local societies may not be quite complete. If any have been omitted, or any details need to be updated, the secretaries concerned are invited to write to the Editor (c/o Messrs Sidgwick & Jackson (Publishers), Ltd, 1 Tavistock Chambers, Bloomsbury Way, London WC1), so that the relevant notes may be included in the 1980 *Yearbook*. There is now a permanent public exhibition at the Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, Sussex. It is open on weekdays between 2 and 5.30 p.m., and on Saturdays, Sundays and public holidays from 10.30 to 5.30 p.m. Admission charges: adults 50p, children and OAPs 25p. The Exhibition covers the fields of modern astronomy, the development of telescopes, the history of the Observatory and of the Castle. There is a tea room (June-September), a souvenir shop and free parking.

1979 YEARBOOK of ASTRONOMY

Edited by
Patrick Moore

The Yearbook continues to grow in popularity throughout the world and is often quoted in press review as a 'must' for all astronomers, amateur and professional.

As usual, the Editor maintains a nice balance of articles from old friends and new contributors, and is particularly pleased to have 'scooped' an article from Professor Charles T. Kowal of California, on his discovery of 'Chiron'.

The 'general notes' in the monthly charts have been reinstated as many readers wrote protesting at the omission last year. As always the charts and the notes of monthly phenomena have been prepared by Dr. J. G. Porter, to whom we are most grateful.

The 1979 Yearbook contains articles on:

The Shoulders of Giants	R. Maddison
George Biddell Airy	Peter J. Garbett
Chiron: a New Type of Object in the Solar System	Charles T. Kowal
Lunar Transients: their History and Our Theories	Michael Bode
The Atmospheres of Uranus and Neptune	Garry E. Hunt
The Discovery of the Rings of Uranus	Gordon E. Taylor
The 'Maunder Minimum' in Perspective	Cicely N. Botley
Brighter than a Million Suns	David A. Allen
Supernovae in History	F. Richard Stephenson
Journey to the Centre of the Galaxy	Heather Couper

There is a concluding section devoted to recent advances in astronomy.

0 283 98485 6

£2·95

Sidgwick & Jackson Limited
1 Tavistock Chambers, Bloomsbury Way
London WC1A 2SG

1979 YEARBOOK OF ASTRONOMY PATRICK MOORE Sidgwick & Jackson